

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

April 5, 1965

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Letter 1, Project A-833
"A Study of a Lightweight Aggregate Concrete for
Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from March 1 to March 31, 1965

Gentlemen:

Work on the project during the month of March 1965, consisted essentially of the following:

1. Conferences (personal and telephone) with members of the Georgia Highway Bridge Department with respect to the conduct of the project. Major items discussed were the design criteria and dimensions of the full-size bridge girders which will be tested. A decision was made to utilize the latest standard 40 ft. girder.
2. A review of the design of the girders has been initiated utilizing specific values of creep and shrinkage instead of the usual method of allowing for a specific prestress loss.
3. Tentative arrangements have been made with the Macon Prestressed Concrete Company, Macon, Georgia, to cast the girders and to provide storage space for the testing period.
4. Arrangements have been made with two lightweight aggregate producers to furnish aggregate for both the field tests as well as for the lab tests.

The two companies who will furnish the lightweight aggregate are:

- a. Georgia Lightweight Aggregate Company
Atlanta, Georgia
 - b. Clinchfield Coal Company
Dante, Virginia
5. Re-assembly of laboratory test equipment has been started.

Respectfully submitted,

B. B. Mazanti
Project Director

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

May 3, 1965

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State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Letter 2, Project A-833
"A Study of a Lightweight Aggregate Concrete for
Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from April 1 to April 31, 1965

Gentlemen:

Work on the project during the month of April 1965, consisted essentially of the following:

1. Planning the effort connected with the casting and testing of the pre-stressed girders.
2. Laboratory tests on lightweight aggregates and experimental evaluation of methods of attaching SR-4 strain gages to pre-stressing strands.
3. Continued review of girder design.
4. Re-assembly and re-design of laboratory test equipment.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

July 8, 1965

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State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

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and the Experiment Station Security Office.

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Letter 3, Project A-833
"A Study of a Lightweight Aggregate Concrete for
Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from June 1 to June 30, 1965

Gentlemen:

Work performed during the month of June consisted primarily of planning for the construction and testing of full sized bridge girders. Equipment and supplies were ordered and central, strain gage monitoring equipment was designed and constructed.

Bids were requested for the construction of three 40 ft. prestressed bridge girders and a purchase order was awarded to the Macon Prestressed Concrete Company, Macon, Georgia. In addition to the construction of the girders, the Company will also provide storage space for the girders during the testing period.

Techniques for the application of strain gages to the prestress strands have been developed and several installations have been tested in the laboratory. It appears that some difficulty may be encountered with correlation between strand load and gage reading due to initial curvature of the strands. A field check of this problem will be made prior to the casting of the test girders to determine if the same difficulties will exist with the full scale tests.

It is now planned to cast the girders about the last week in July.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

August 8, 1965

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and the Experiment Station Security Office.

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Monthly Progress Letter 4, Project A-833
"A Study of a Lightweight Aggregate Concrete for
Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from July 1 to July 31, 1965

Gentlemen:

Work performed during the month of July consisted of continued planning and organization in connection with the testing of full-sized bridge girders. Due to difficulties by Georgia Tech in scheduling personnel to work in the field as well as with difficulties by the Macon Prestressed Concrete Company in scheduling their operations, the casting of the girders has been postponed until August 10.

A field check of the proposed method for the application of gages to the prestress strands was made during this period. A single strand of a girder was "patched" with a quick-setting epoxy and a Type A-3, SR-4 gage cemented to the "patch" with Eastman 910 cement. The strand was then stressed and released, in load increments, several times. During the operations strain, jack loads and strand elongations were measured. Good correlation was obtained between the various factors and the problem of strand curvature, as mentioned in Progress Letter 3, does not appear to be serious.

It is anticipated that work connected with laboratory creep testing will begin about the latter part of August.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

November 9, 1965

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State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Letter 6, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from October 1 to October 31, 1965

Gentlemen:

Work on the project during the month of October 1965 consisted
essentially of the following:

1. Continued monitoring of instrumentation on full-sized prestressed girders.
2. Analysis of data being obtained from the full-sized girder tests.
3. Design, fabrication and checkout of equipment for testing laboratory cylindrical specimens of semi-lightweight concrete.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

REVIEW

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FORMAT 1-8 1966 BY HL

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

December 9, 1965

NOTICE

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Letter 7, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Covering the Period from November 1 to November 30, 1965

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Gentlemen:

During this period the laboratory creep testing of the semi-lightweight concrete mixes was initiated.

Batches of semi-lightweight concrete were mixed for strength versus age studies as well as for some creep studies. New techniques were developed for the application of gage plugs to the creep specimens. This involved the use of a non-shrink type cement to secure stainless steel gage plugs into pre-formed holes in the concrete cylinders. Good results are being obtained in this manner and the problem of loose gage plugs has been practically eliminated.

Additional semi-lightweight specimens (made with the two lightweight aggregates being used) will be cast and subjected to various stress applications.

Instrumentation of the full-size prestressed bridge girders continues to be monitored and the data analyzed.

Respectfully submitted,

for B. B. Mazanti
Project Director

BBM/c

REVIEW

PATENT 12-24 1965 BY Russ
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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

February 9, 1966

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Letter 8, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from January 1 to January 31, 1966

Gentlemen:

Work during this period consisted of continued monitoring of instrumentation on the specimens cast and loaded previously.

Two additional batches of lightweight concrete were mixed and "creep" specimens were prepared for testing. Due to undetermined causes, failure of some specimens soon after loading caused the removal of load from all specimens. This necessitated the discarding of both groups of test cylinders. These series will be re-cast and tested in the near future.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

March 8, 1966

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Letter 9, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from February 1 to February 28, 1966

Gentlemen:

During this period, additional creep specimens of semi-lightweight concrete were cast, cured and loaded. Monitoring of instrumentation on prior work continued and reduction of the data is in progress. Graphical representation of the results obtained will be presented in the next Quarterly Progress Report.

Work planned for the future includes:

1. Loss of prestress studies

This will include semi-lightweight concrete from Galite and Clinchlite. Members of rectangular cross-section of each will be subjected to externally applied, prestress-type loading in specially constructed loading frames. It is anticipated that two levels of prestress loads will be applied to each concrete mix. The loading frames are to be similar to those used by the Portland Cement Association (see J. of Prestressed Concrete Inst., Vol. 9, No. 2, pp 69-93, Apr. 1964). Modifications to the PCI design have been made and work on the equipment will begin soon.

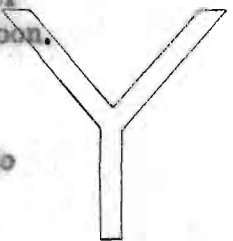
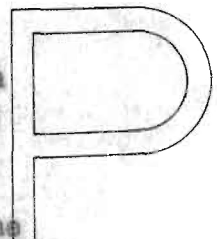
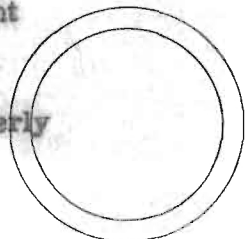
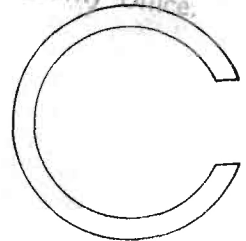
2. Stress transfer length studies

This will include both types of concrete and is intended to determine the stress transfer-length relationship as the prestressing force is transmitted to the concrete.

Small sized beams will be internally prestressed (pre-tensioned, bonded) and the strand stress measured by means of SR-4 wire resistance gages mounted on the strands.

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This work is not scheduled to begin until the loss of prestress studies are under way.

Respectfully submitted,

B. B. Mazanti
Project Director

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

May 9, 1966

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and the Experiment Station Security Office.

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Letter 10, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from April 1 to April 30, 1966

Gentlemen:

During the month of April, the testing of additional semilightweight concrete laboratory specimens was begun. The purpose of this test series is to determine the effect of "age at time of loading" on the creep characteristics of the concrete.

The concrete cylinders are placed under identical, constant loads at various ages after being cast and the resulting deformation with time is recorded. From this data, a comparison can be made between the creep behavior of the concrete when prestressed at different ages.

Both Galite aggregate and Clinchlite aggregate concrete were tested. The basic mixes are as shown in Quarterly Progress Report 4, April 8, 1966. The following table shows pertinent data with respect to this series of tests.

Type Concrete	Date Cast	Date Loaded	Age Loaded	Strength at Load Date
Clinchlite	4/12/66	4/16/66	4 day	5180 psi
		4/19/66	7 day	5710 psi
Galite	4/19/66	4/23/66	4 day	5200 psi
		4/26/66	7 day	5500 psi

Note: All specimens loaded to 2550 psi.

Additional specimens will be loaded at 21 day ages.

Future Work

Equipment is being assembled for the "loss of prestress" tests on eccentrically loaded, short, plain concrete beams and for "stress transfer" tests on concentrically prestressed beams. The "loss of prestress" tests are scheduled to begin during the last week of May.

Plans are being formulated for the load tests on the full-sized prestressed girders.

Respectfully submitted,

B. B. Maxanti
Project Director

BBM/c

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

June 16, 1966

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and the Experiment Station Security Office.

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Letter 11, Project A-833
"A Study of a Lightweight Aggregate Concrete for
Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from May 1 to May 31, 1966

Gentlemen:

During this time period, work was continued with respect to the assembly of equipment for the stress-transfer tests and for the loss of prestress tests.

Data were collected from the laboratory creep tests presently in progress. These data are being reduced and graphical representations prepared.

No additional tests were begun during this month.

Respectfully submitted,

B. B. Mazanti
Project Director

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

August 8, 1966

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**State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia**

**Attention: Mr. H. H. Huckeba
State Highway Planning Engineer**

**Subject: Monthly Progress Letter 12, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from July 1 to July 31, 1966**

Gentlemen:

During this time period the first "Loss of Prestress" beam was cast and loaded. This beam is end-loaded in an eccentric manner so that the concrete stresses vary from approximately 2200 psi to zero across the beam depth. The beam is instrumented with gage plugs on all four faces and the concrete deformations are measured by means of a 10 in. Whittemore gage.

One beam was cast and loaded to determine the stress-transfer characteristics of the Clinchlite semi-lightweight concrete. The data from this test is being analyzed and will be presented in the next Quarterly report.

Respectfully submitted,

**B. B. Mazanti
Project Director**

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

September 12, 1966

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and the Experiment Station Security Office.

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Monthly Progress Letter 13, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from August 1 to August 31, 1966

Gentlemen:

Work during this time period consisted of the following:

1. Continued monitoring of the work in progress in the lab which consists of creep specimens under constant-load and the "Loss of Prestress" beam.
2. Casting of a Galite semi-lightweight concrete beam to determine the stress-transfer characteristics.
3. Continued work on the assembly of a second test frame for "Loss of Prestress" studies on the Galite semi-lightweight concrete.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

November 17, 1968

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State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. H. H. Huckleba
State Highway Planning Engineer

Subject: Monthly Progress Letter 14, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from October 1 to October 31, 1968

Gentlemen:

During this time period, work consisted of the following:

1. Continued monitoring of the laboratory tests in progress and evaluation of data.
2. Casting, instrumenting and loading a Galite semilightweight concrete beam for "Loss of Prestress."

Respectfully submitted

B. B. Mazani
Project Director

BBM/c

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GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

December 18, 1966

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State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. H. H. Huekeba
State Highway Planning Engineer

Subject: Monthly Progress Letter 15, Project A-823
"A Study of a Lightweight Aggregate Concrete for
Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from November 1 to November 30, 1966

Gentlemen:

During this time period, work consisted of continued monitoring of the
laboratory tests in progress and evaluation of the data.

No new tests are planned since the project is scheduled for termination
as of February 28, 1967.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

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A-833

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

February 2, 1967

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**State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia**

**Attention: Monthly Progress Letter 16, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from January 1 to January 31, 1967**

Gentlemen:

During this time period, work accomplished has been with respect to the analysis of data for presentation in the Final Report which is due February 28, 1967.

Respectfully submitted,

**B. B. Mazanti
Project Director**

BBM/c

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

June 4, 1965

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and the Experiment Station, Georgia Tech.

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Quarterly Progress Report 1, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from March 1 to May 31, 1965

Gentlemen:

Work on the project during the period covered by this report consisted primarily of planning with respect to the manufacturing and testing of the full size bridge girders. Other work consisted of the re-assembly of the loading frames for the laboratory testing phase of the project.

In connection with the full size girders, the following has been accomplished:

1. It was decided to test 3 standard, 40 ft. girders. One normal weight concrete, one semi-lightweight concrete girder made with aggregate from Georgia Lightweight Company, Atlanta, Ga., and one semi-lightweight concrete girder made with aggregate from the Clinchfield Coal Co., Dante, Virginia.
2. Instrumentation arrangements have been selected and monitoring control boards are being constructed.
3. Supplies to be used in the instrumentation work have been ordered.
4. Requests for bids to furnish the girders and storage of the girders have been sent out.

It was originally planned to begin the girder tests about June 12, 1965. Personnel problems have caused a revision of the estimated starting date and it is now planned to begin girder tests about July 15, 1965.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

October 11, 1965

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and the Experiment Station Security Office.

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Quarterly Progress Report 2, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from June 1 to September 30, 1965

Gentlemen:

During this quarter, efforts were concentrated on the planning aspects and the construction of three full sized bridge girders and the subsequent monitoring of the instrumentation on the girders.

The girders are 40 ft. in length and each is made of a different concrete mixture. Two are made with semilightweight concrete and one with normal weight concrete. One of the semilightweight concrete mixes utilizes a local (Georgia produced) lightweight aggregate and the other lightweight aggregate is shipped in from out of state. The Georgia aggregate is an expanded shale material and is called Galite. The out of state aggregate is also expanded shale manufactured at Clinchfield, Virginia and is called Clinchlite.

The girders were cast by the Macon Prestressed Concrete Company in Macon, Georgia. They were cast in a line on the same bed, utilizing the same prestress strands.

The strands were first placed in position and tensioned with a "pre-load" force of 1000 pounds. Epoxy cement "patches" were applied to the strands at certain locations and electric resistance strain gages were cemented to the epoxy. After lead wires were brought out from the girder forms and the gage installations were waterproofed, the strands were stressed to their full prestress level.

The girders were cast one at a time in order to utilize the one set of forms available. In order to produce about the same strength at the time of cutting the strands, the first girder cast was made with the "weaker-aggregate" concrete (Galite), the next with the Clinchlite aggregate and the last with the crushed stone aggregate

Prior to the cutting of the strands, the exterior surfaces of the girders were instrumented with strain gages in order to monitor concrete strains.


The girders were "prestressed" on August 16, 1965 and placed in a storage area on the lot of the Macon Prestressed Concrete Company. Since that time, the gages have been periodically monitored.

As indicated in Monthly Progress Letter 5, many of the strain gages have been either shorted or damaged during the concreting operations. It was expected that many gages would be lost, however, a sufficient number appear to be in good working order.

The data are being reduced and correlation studies are being made.

Creep tests on the concrete are to be carried out in the laboratory and equipment is being developed and assembled for this purpose. These tests will commence in the near future.

Respectfully submitted,

 B. B. Mazanti
Project Director

BBM/c

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

January 9, 1966

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Quarterly Progress Report 3, Project A-888
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from October 1 to December 31, 1965

Gentlemen:

Work on the project during this quarter consisted primarily of laboratory testing. Concrete mixes were batched-out and adjusted for the batching conditions being used.

The following basic semi-lightweight mixes are being tested:

1. Galite Lightweight Aggregate Mix (per cubic yard)
Cement: 877 lb.
Water: 425 lb.
Coarse Agg. (Galite): 950 lb.
Fine Agg. (Sand): 1170 lb.
2. Clinchlite Lightweight Aggregate Mix (per cubic yard)
Cement: 658 lb.
Water: 417 lb.
Coarse Agg. (Clinchlite): 1138 lb.
Fine Agg. (Sand): 1148 lb.

(All weights are based on an oven dry basis.)

Trial batches were put-up to check-out the installation of gage plugs in a manner different from that which had been used in the past. The present method of installing gage plugs is as follows:

1. Solid, smooth, cylindrical steel inserts are cast into the concrete cylinder, 10 in. on center, and held in place by means of set screws in the metal forms.

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2. After the concrete has hardened, the inserts are pulled-out and replaced by stainless steel gage plugs. The plugs are held in position by a locating bar and cemented into the concrete specimens by means of a "non-shrink" grout (Por-Rock).

Although some gage plugs are still found to be loose, the number is much less than in the past when the gage plugs were being cast into the fresh concrete.

At the present time, creep testing of lightweight aggregate concrete is being conducted as follows:

Galite Semi-lightweight Concrete Cylinders

Loaded at 4 days age to two stress levels by means of prestress bars. Loads vary due to shrinkage, creep and relaxation of the steel.

Clinchlite Semi-lightweight Concrete Cylinders

a. Loaded at three different ages to the same stress level by means of prestress bars. Loads vary due to shrinkage, creep and relaxation of the steel.

b. Loaded at 4 days age to two different stress levels. Loads remain constant throughout duration of test.

Additional creep tests of both mixes are planned. The tests will be similar in nature to those under way at the present time.

Respectfully submitted,

for B. B. Mazanti
Project Director

BBM/c

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

April 8, 1966

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and the Experiment Station Security Office.

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Quarterly Progress Report 4, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from January 1, 1966 to March 31, 1966

Gentlemen:

Work performed on the project to date has consisted of the following:

1. Three 40 ft. prestressed, concrete bridge girders were cast at Macon, Georgia at the yard of the Macon Prestressed Concrete Company. Prior to the casting, the prestress strands were instrumented in order to monitor the change in the steel stress before and after prestressing the girders. Strain gages were also attached to the exterior surfaces of the concrete to monitor changes in length of the girders.

It was hoped that data from this instrumentation would allow correlation of prestress load with the deformation of the girders. It was recognized that a number of the gages would be damaged during the casting process and that others would be lost due to moisture in the concrete; however, the data appears to be extremely erratic and indicates that many more gages were damaged than was anticipated. Evaluation of the data is still in progress although it is presently believed that dependable results will not be obtained from this portion of the project.

After evaluation of the results are complete, the girders will be utilized for load capacity tests. Since the internal instrumentation appears to be functioning improperly, only the external load and deformation characteristics can be determined; however, this will provide a comparison between the capacities of a standard or normal weight concrete girder and the capacities of girders made

with each of the two lightweight aggregates under consideration. Such a comparison should be of considerable value to the Highway Department with respect to a decision as to the possible use of the semi-lightweight aggregate concrete.

2. Laboratory studies of the creep and shrinkage characteristics of concrete made from the two lightweight aggregates are in progress. All long-term testing is being conducted in a 72° F, 50% relative humidity environment after an initial curing period in 72° F, 100% humidity conditions. The creep loads are, in some cases, of a constant nature while, in other test series, the loads are variable (diminishing).

Presented in this report are graphs indicating the creep and shrinkage characteristics of the two lightweight aggregate concretes with respect to the present age of the concrete.

These results are for concrete cylinders under constant stress at two stress levels. Additional cylinders have been loaded to stress levels different from that reported here, however, the time after loading is insufficient to utilize the results.

The following basic semi-lightweight mixes are being tested:

1. Galite Lightweight Aggregate Mix

Cement:	677 lb.
Water:	425 lb.
Coarse Agg. (Galite):	950 lb.
Fine Agg. (Sand):	1170 lb.

2. Clinchlite Lightweight Aggregate Mix

Cement:	658 lb.
Water:	417 lb.
Coarse Agg. (Clinchlite):	1188 lb.
Fine Agg. (Sand):	1148 lb.

(All weights are based on an oven dry basis and are for a cubic yard of concrete.)

Results:

The results are presented in the form of graphs.


Figures 1 and 2 show the relation between strain and time after loading for the Galite Aggregate concrete. These curves have typical shapes for

plots of this type. The strain rate is relatively high at first and gradually diminishes. The plot of Creep Strain vs Time (Fig. 2) shows the relation to be either a curve of constant slope or a curve consisting of a series of straight lines. With additional data (with respect to time after loading) these curves may be extrapolated to ages corresponding to the anticipated life of the structure and thereby a prestress loss may be calculated.

Figures 3 and 4 show the same relations for the Clinchlite Aggregate concrete.

Figure 5 shows the relationship between creep strain and the stress-strength ratio. Obviously, this plot is time dependent and a two month time period has been used here. When sufficient data has been accumulated and the anticipated-life strain can be predicted, terminal curves can be plotted. Additional specimens are being tested in order to better define the relationships, however, it appears at present that an approximately linear relation will exist at least up to the maximum ratios used. The plots will be brought up to date as data becomes available.

Respectfully submitted,

B. B. Mazanti 
Project Director

BBM/c

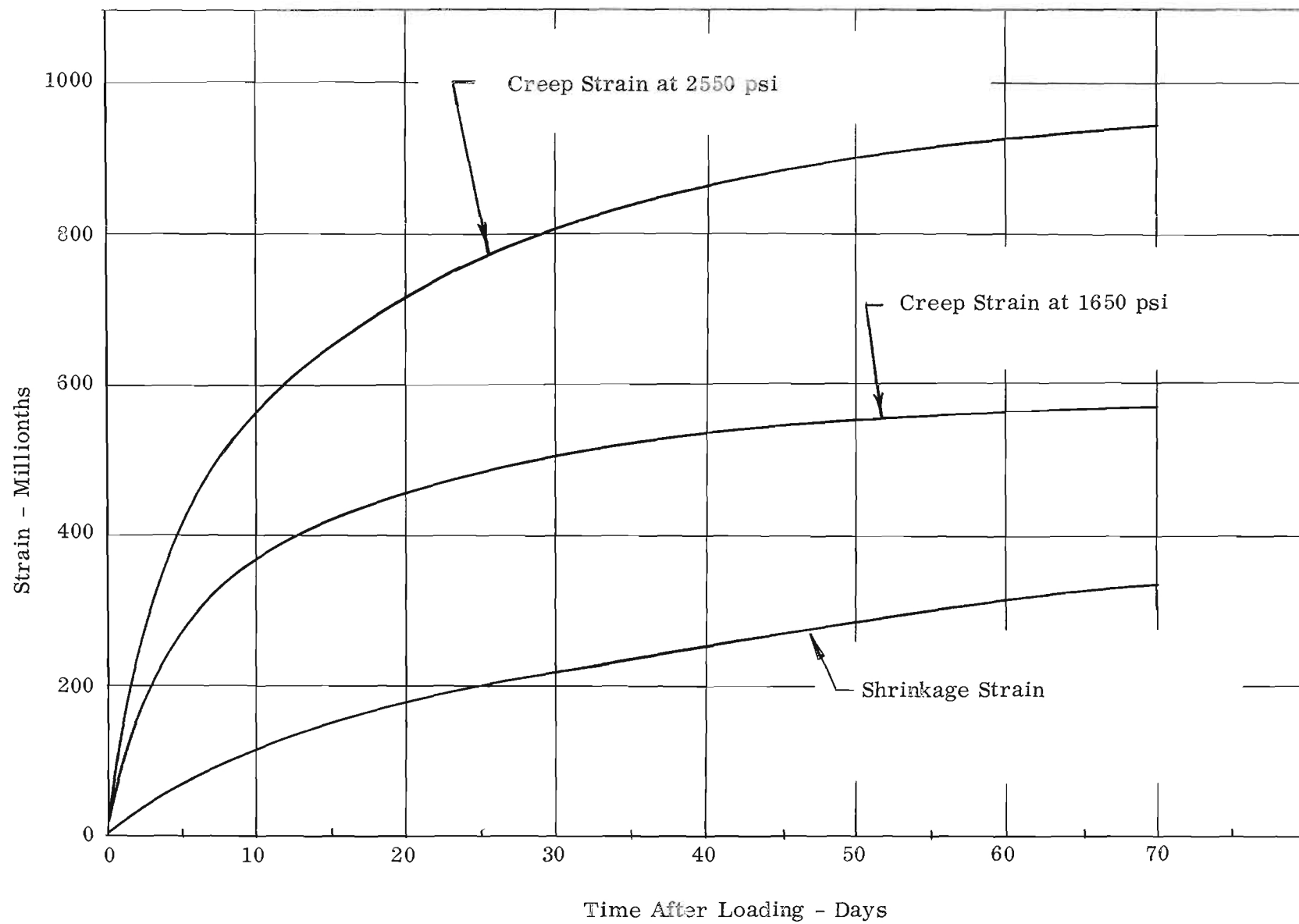


Figure 1. Creep and Shrinkage of Galite Concrete Under Constant Load.

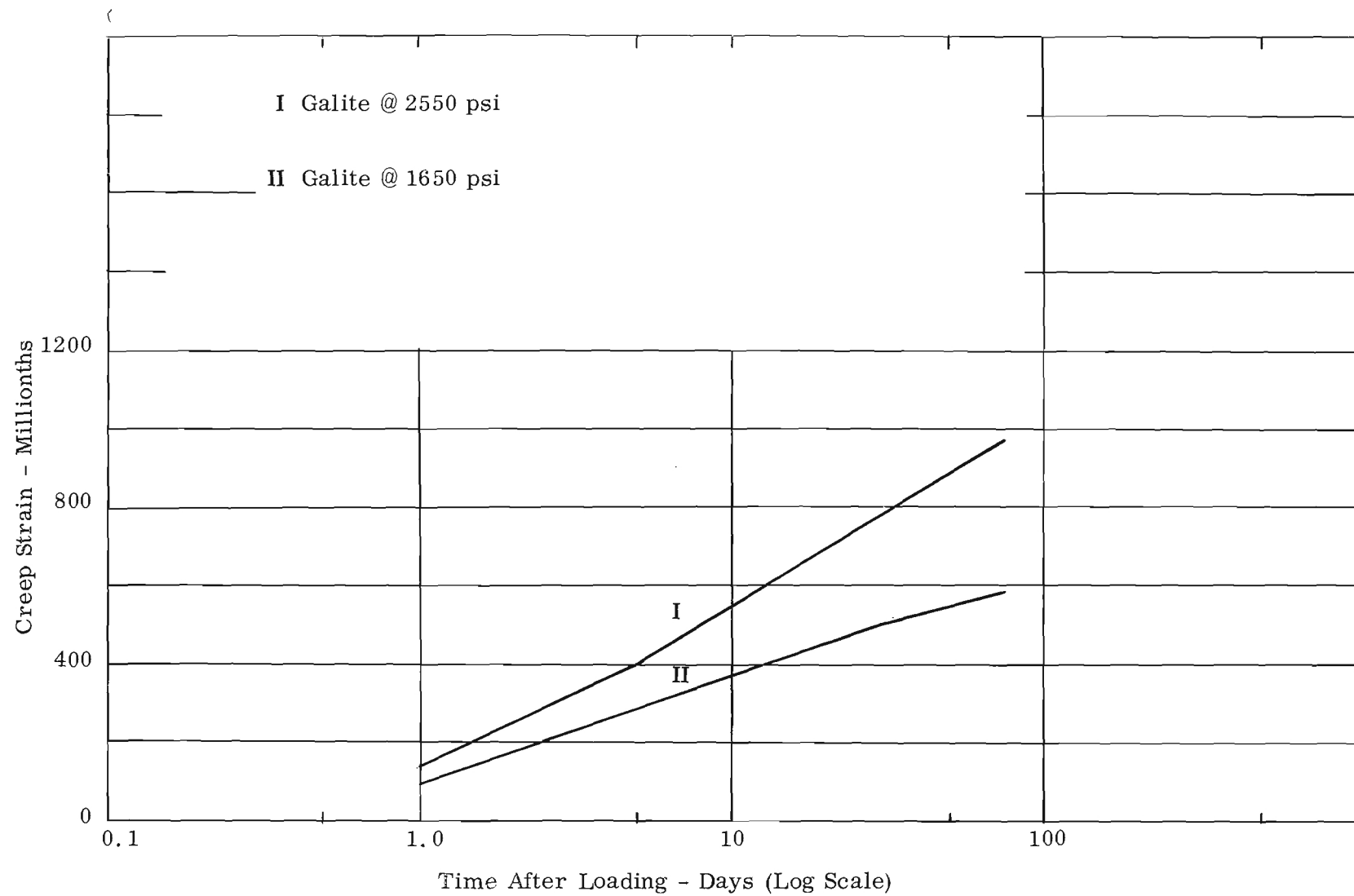


Figure 2. Creep Strain of Galite Concrete Under Constant Load.

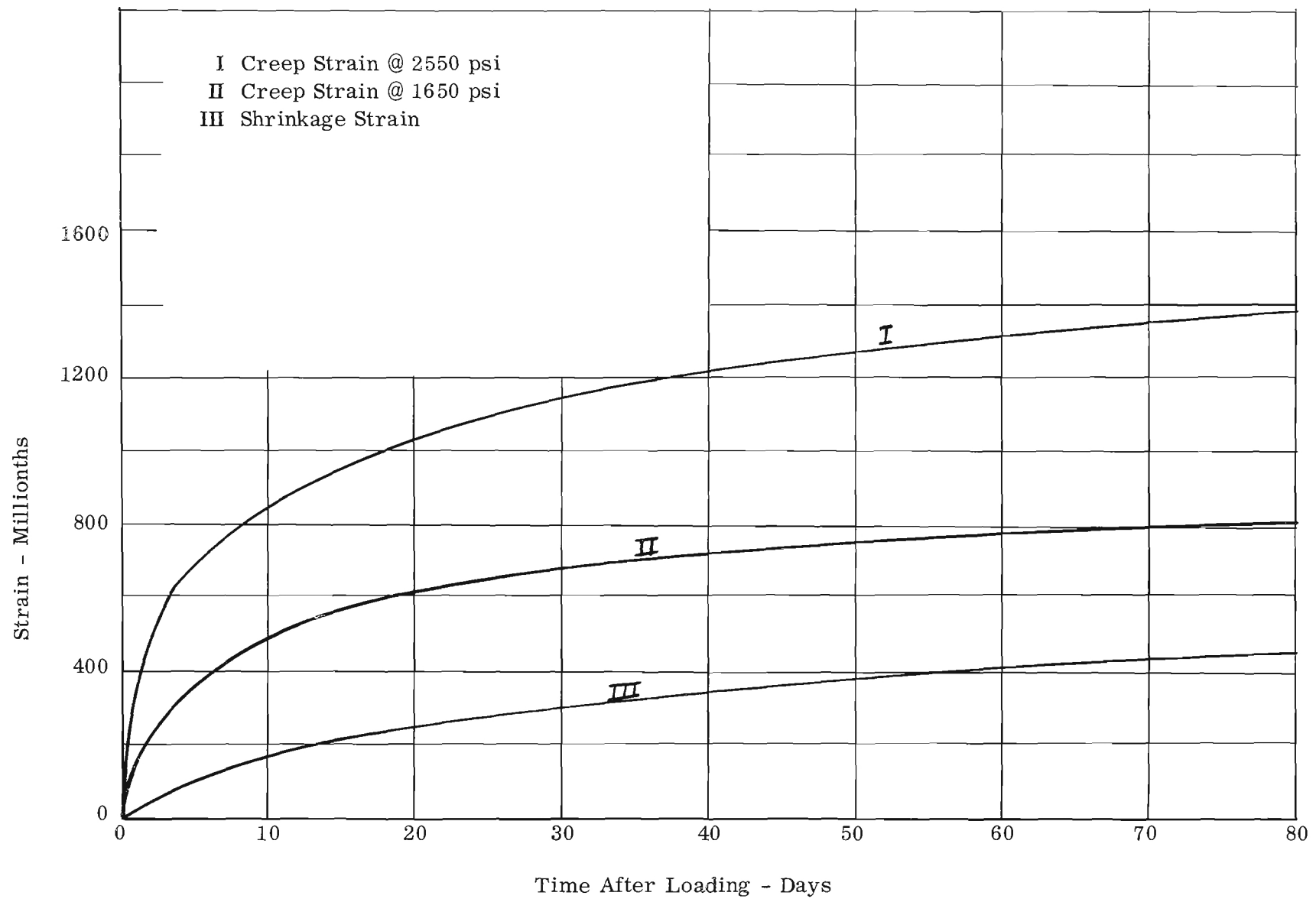


Figure 3. Strain-Time Relation for Clinchlite Concrete Under Constant Load

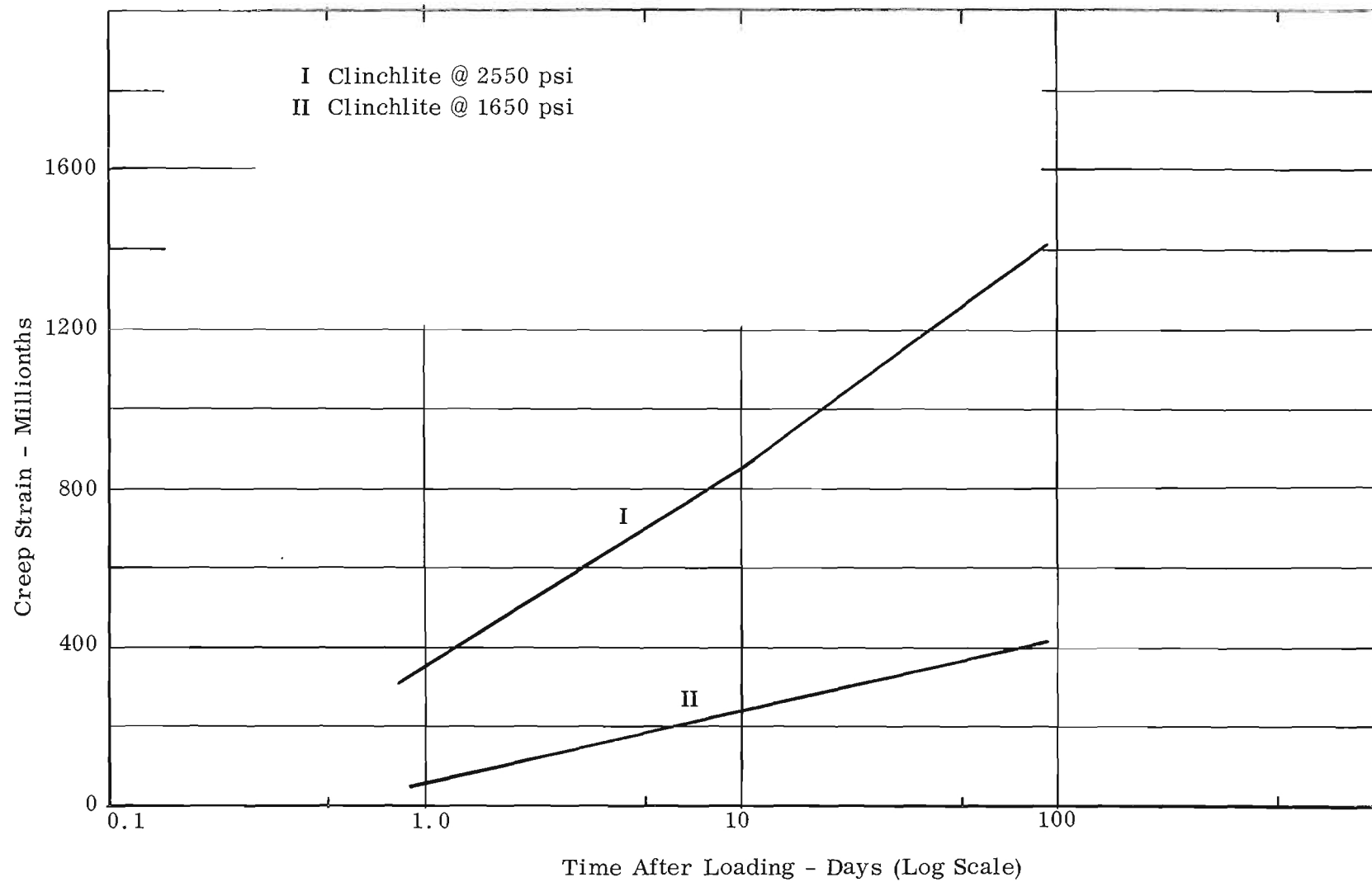


Figure 4. Creep Strain-Time Relation for Clinchlite Concrete Under Constant Load

- I Clinchlite Semi-Lightweight Concrete
- II Galite Semi-Lightweight Concrete

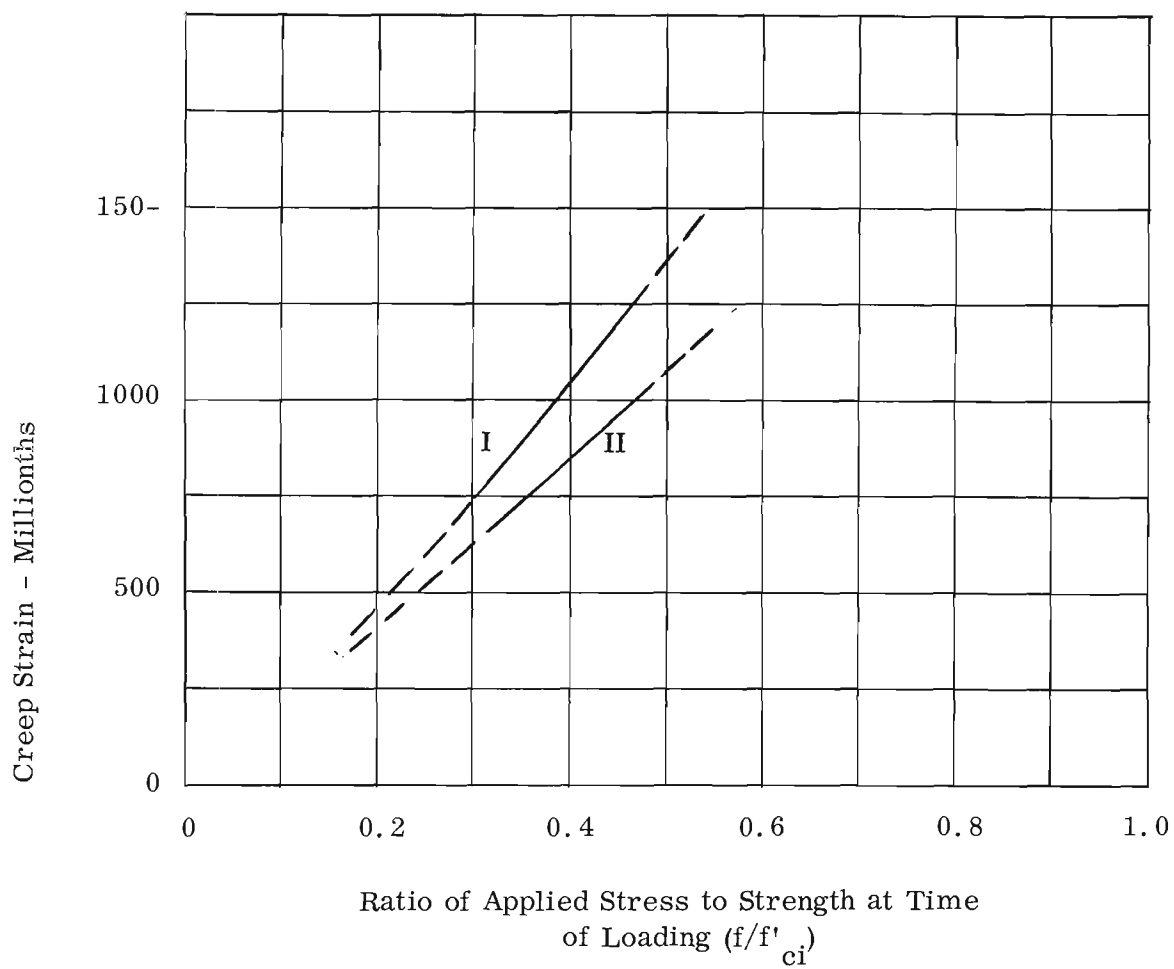


Figure 5. Creep Strain of Semi-Lightweight Concrete vs Stress-Strength Ratio for Constant Loading.

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

July 22, 1966

State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. E. C. Parrish
State Highway Planning Engineer

Subject: Quarterly Progress Report 5, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from April 1 to June 30, 1966

Gentlemen:

During this time period, work was continued on the assembly of the loading frames for the "loss of prestress" studies and for the "stress transfer" studies. Concrete cylinders of both Galite and Clinchlite aggregate concrete were loaded at various ages after casting to the same constantly-applied compressive stress level. The resulting creep is currently being monitored.

Loss of Prestress Studies

The purpose of these tests will be to determine the prestress loss which occurs in the different semi-lightweight concretes under consideration when subjected to prestressing under applied stress conditions simulating those in practice. Prestressing is to be accomplished by 7-wire strands and the change in prestress will be monitored by both strain gages on the strands and by an independent measure of the load applied to the concrete.

These tests, originally scheduled to begin during this time period, will begin about the end of July. The delay is due to a change in emphasis of work to the stress transfer tests.

Stress Transfer Tests

Equipment for prestressing concrete beams approximately 4 in. by 4 in. by 8 ft. has been assembled and a trial beam has been cast.

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The trial beam was 3 1/2 in. by 4 in. by 8 ft. and a 7/16 in. strand was utilized. Two opposite exterior faces of the concrete were instrumented with gage points on 2 in. centers and after a curing period of 4 days, the prestress was rather slowly applied by release of the hydraulic pressure in the prestress jack. Deformation of the beam was measured between each set of gage points by the use of a Whittemore gage.

The results of this trial beam indicated the necessity for several refinements with respect to both the prestress application and the deformation measurement.

Additional tests will be accomplished during the next two to three months, beginning in July.

Effect of Age at Loading on Creep

Cylindrical specimens of both Galite and Clinchlite semi-lightweight concrete were loaded at ages of 4, 7 and 21 days after casting. The loads are at stress levels of 2550 psi and maintained constant by the hydraulic load cells. Creep data are being taken and the results being graphed.

The results are not sufficient for presentation at this time.

Creep Under Constant Load

The creep-time behavior of the Galite semi-lightweight concrete has been brought up to date. The results are presented in Figures 1 through 3.

Figure 1 shows the creep versus log time relation for Galite semi-lightweight concrete loaded at different stress levels. Included on this graph are two curves from work included in Phase I of this project. It is evident that the creep-time curves are quite similar for both the present work and the earlier study. At lower values of "applied stress to strength at time of loading," the curves are essentially linear with a change in slope occurring about 2 to 3 weeks after loading. As the load-strength ratio ($f/f'c$) increases, the change in slope does not occur and the creep is represented by a continuous straight line.

The creep versus $f/f'c$ relation for the present work is shown in Figure 2. Included are curves for the Galite at ages of 60 and 160 days and for the Clinchlite at an age of 60 days.

Figure 3 shows the same relation for the Galite semi-lightweight concrete from the present work and that of Phase I. The present creep-time curves were extrapolated to 250 days and combined with the Phase I

results at that age. The combined curve is linear to about $f/f'_c = 0.6$, becoming slightly concave upward thereafter. The good correlation between the present work and the older study provides a basis for confidence in the reproduceability of creep data and in the use of such data in design.

Respectfully submitted,

B. B. Mazanti[✓]
Project Director

BBM/c

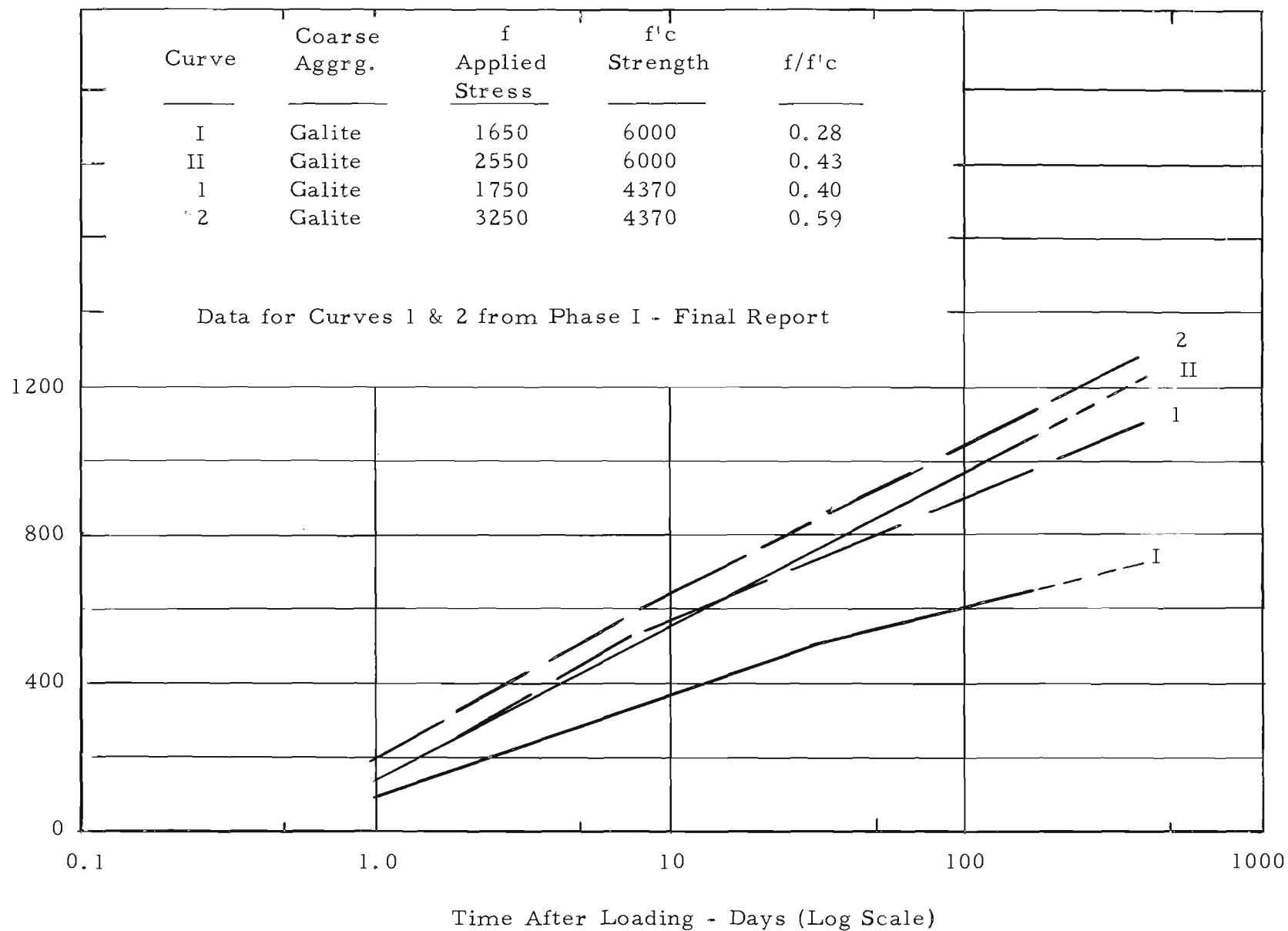


Figure 1. Creep Strain of Semi-Lightweight Concrete Under Constant Load

- I Clinchlite Semi-Lightweight Concrete @ 60 days
- II Galite Semi-Lightweight Concrete @ 60 days
- III Galite Semi-Lightweight Concrete @ 160 days

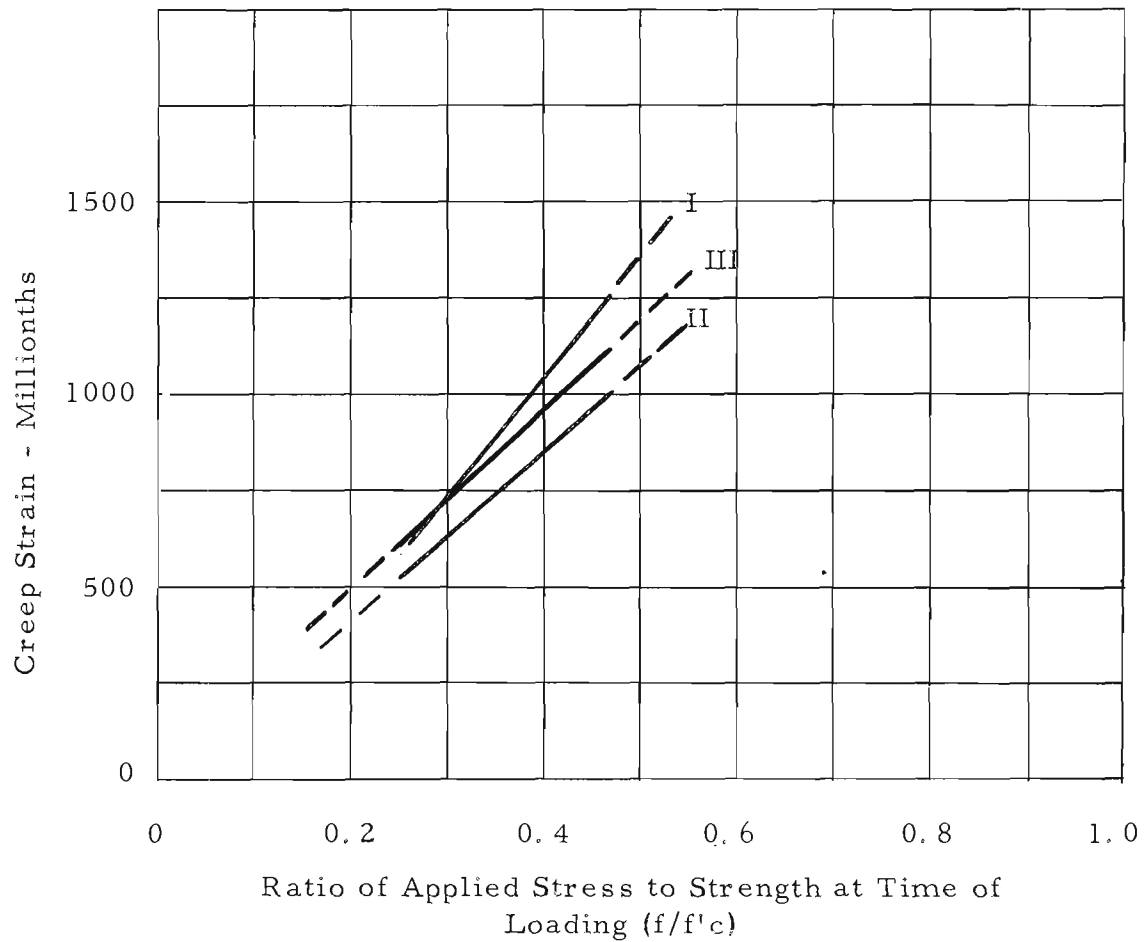
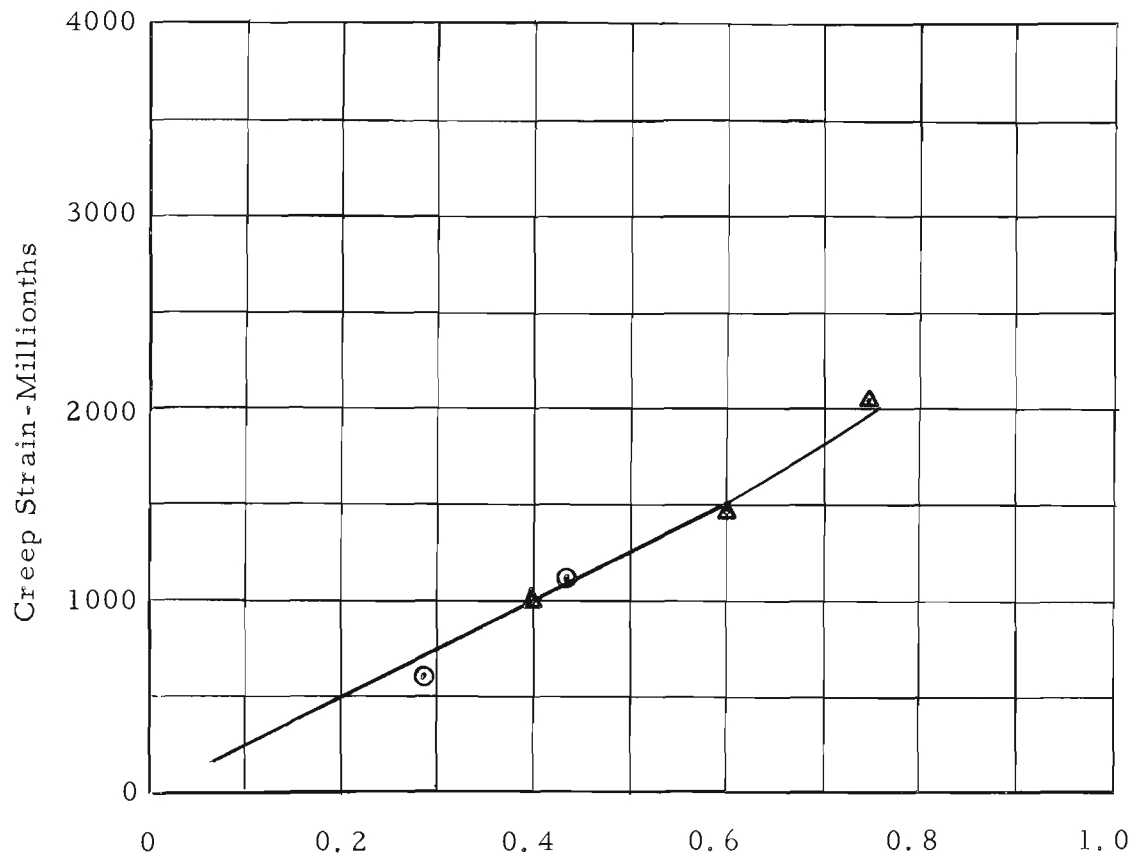


Figure 2. Creep Strain of Semi-Lightweight Concrete versus Stress-Strength Ratio for Constant Loading

Time After Loading = 250 days

⊙ Data from Present Work (Extrapolated)

▲ Data from Phase I



Ratio of Applied Stress to Strength at Time of
Loading (f/f'_c)

Figure 3. Creep Strain of Galite Semi-Lightweight Concrete versus Stress-Strength Ratio for Constant Loading

GEORGIA INSTITUTE OF TECHNOLOGY**ENGINEERING EXPERIMENT STATION****ATLANTA, GEORGIA 30332**

October 18, 1966

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State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Quarterly Progress Report 6, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from July 1 to September 30, 1966

Gentlemen:

During this quarter efforts were concentrated in the following areas:

1. Monitoring of the work in progress in the lab which includes the creep specimens under constant load.
2. Casting and loading the Clinchlite semilightweight concrete beam for the "Loss of Prestress" study.
3. Casting and loading both Clinchlite and Galite semilightweight concrete beams for the "Stress Transfer" study.

Constant-Load Creep Specimens

The results of this work were presented up-to-date in Quarterly Progress Report 5. Data collected since the presentation in Report 5 would not be sufficient to materially alter the trends indicated therein and consequently, these results will not be included in this report.

Loss-of-Prestress Study

This study involves the eccentric prestressing of 6" x 9" x 36" prisms of concrete. The prestressing is accomplished by the use of a special loading frame which utilizes 4 prestress strands to apply external post-tensioning loads. The loads are caused to act at the 1/3 point of the beam ends with respect to the 9 in. dimension. This induces compressive stresses in the beam which vary linearly from a maximum at one side to zero at the other. This type of loading is used to simulate actual

service loading and, since the loads decrease as the concrete shortens (due to creep and shrinkage), the loss of prestress can be assessed.

At the present time, one Clinchlite semilightweight beam has been under load for approximately two months. The results are shown graphically in Figure 1 in the form of Prestress Loss versus Time after Loading. While the Prestress Loss is shown in terms of percent, it should be recognized that these values were computed from the measured losses and the initial prestress value used. For other initial prestress values, the percent loss due to shrinkage would be in proportion to the ratio of the test load to the actual load.

For this beam, the initial total prestress load was 50.8 kips which induced a maximum compressive stress in the concrete of approximately 1880 psi.

Stress Transfer Study

The purpose of this study was to determine the stress transfer-length characteristics of semilightweight concrete made from the two lightweight aggregates when prestressed.

The concrete was cast in metal forms to produce prisms 3 1/2 inches in width, 4 inches in height and 8 feet in length. The members were each prestressed with a single 7/16 inch diameter, conventional pretensioned strand which passed through the center of the concrete. The strands were in "field condition" in that no cleaning of the strands was done; however, the strands were not rusted and would be representative of strands utilized by a commercial prestressing plant which exercised reasonable care in their operations. Each strand was pretensioned to a load of 18.9 kips. This produced a maximum prestress in the concrete of 1575 psi.


Mechanical gage points were attached to both of the 3 1/2 inch faces of the specimens at the level of the prestressing strand. The gages were located at intervals of 2 inches along the beams beginning 4 inches from an end and extending about 36 inches. A Whittemore mechanical gage was used to measure deformations between the gage points immediately prior to and after the detensioning.

The stress transferred at any position along the beam was assumed to be proportional to the deformation which occurred at that position. The prestress transferred to that which occurred in the section where the deformations became constant.

The results are shown in Figure 2 as graphs of Percent of Steel Stress Transferred versus Distance From End of Member.

For both semilightweight concretes used, the full prestress force was transferred at a distance of approximately 25 inches from the "cut end" of the members.

Respectfully submitted,

B. B. Mazanti 
Project Director

BBM/c

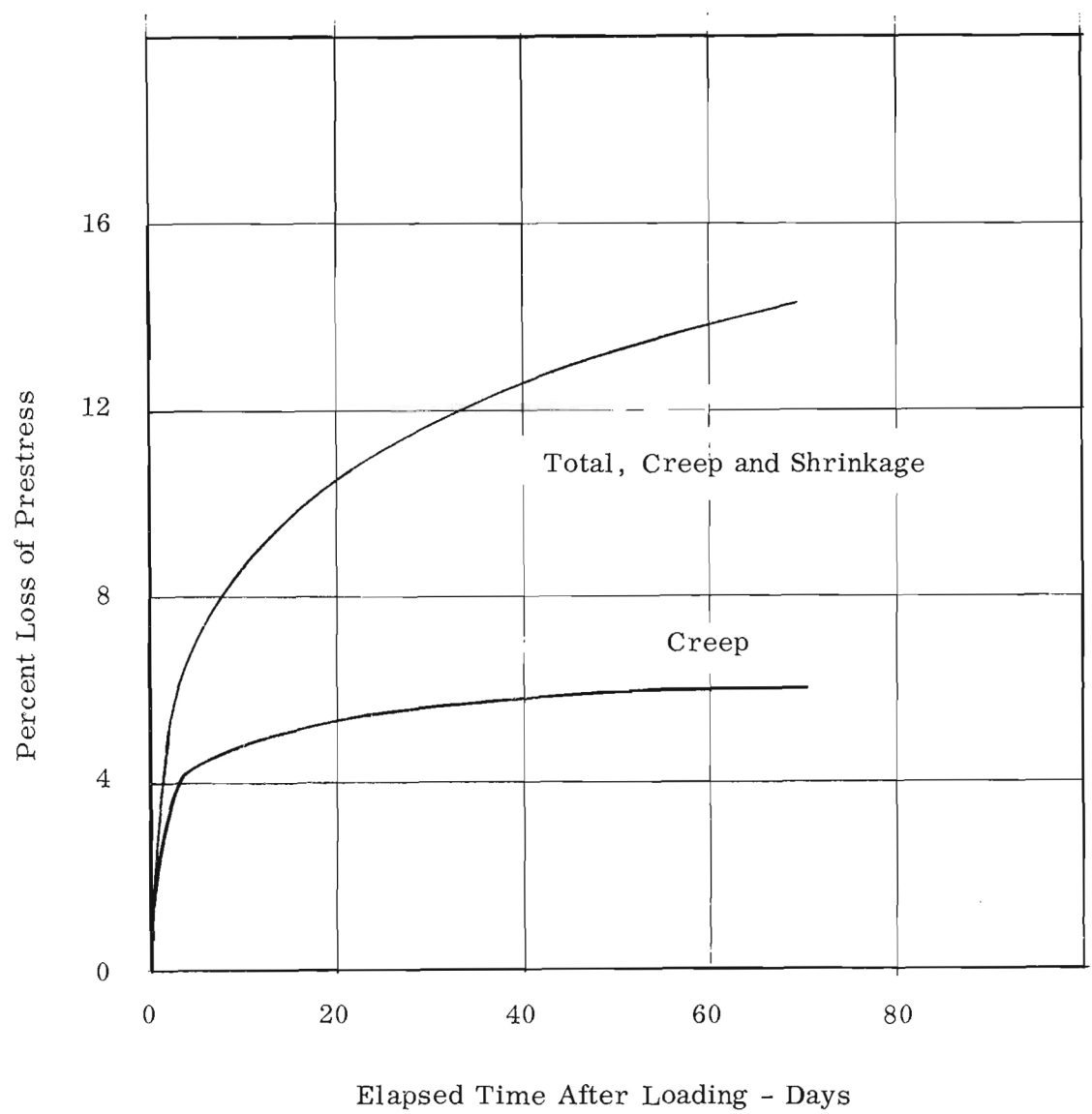


Figure 1. Loss of Prestress, Clinchlite Semilightweight Concrete.

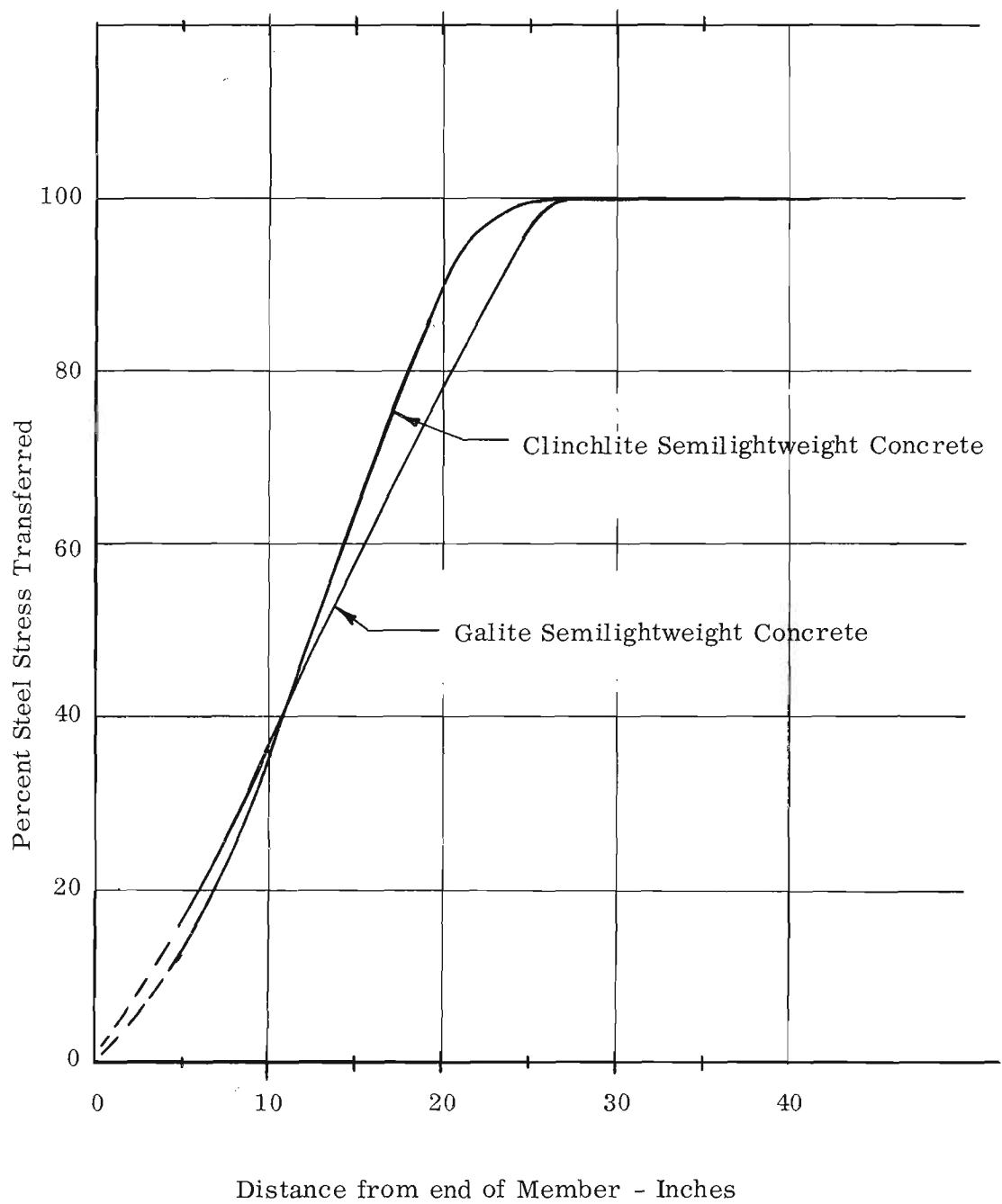


Figure 2. Stress Transfer Length Relation for Semilightweight Concrete.

A-833

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ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

February 2, 1967

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State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. H. H. Huckeba
State Highway Planning Engineer

Subject: Quarterly Progress Report 7, Project A-833
"A Study of a Lightweight Aggregate Concrete
for Prestressed Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from October 1 to December 31, 1966

Gentlemen:

During this time period, work consisted of the following:

1. Continued monitoring of the laboratory tests in progress at the beginning of the time period. These tests include:
 - a. Creep specimens under constant load.
 - b. Clinchlite semilightweight concrete beam for "Loss of Prestress" study.
2. Casting and loading the Galite semilightweight concrete beam for "Loss of Prestress" study.

At present, preparation of the data and results are in progress for presentation in the Final Report on this phase of the project. Since all results will be presented therein, no results of the newly begun tests will be presented at this time.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

September 14, 1967

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State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

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Attention: Mr. L. S. Veal
State Highway Planning Engineer

Subject: Quarterly Progress Report 8, Project A-833
"A Study of a Lightweight Aggregate Concrete for Prestressed
Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from January 1 to March 31, 1967

Gentlemen:

During this time period, work has been concerned with data reduction,
analysis and preparation of the final report.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

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GEORGIA INSTITUTE OF TECHNOLOGY

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ATLANTA, GEORGIA 30332

September 14, 1967

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State Highway Department of Georgia
2 Capitol Square
Atlanta, Georgia

Attention: Mr. L. S. Veal
State Highway Planning Engineer

Subject: Quarterly Progress Report 9, Project A-833
"A Study of a Lightweight Aggregate Concrete for Prestressed
Highway Bridge Girders - Phase III"
Contract No. 6503
Covering the Period from April 1 to June 30, 1967

Gentlemen:

Preparation of the final report is still in progress and work on the
final report has been accomplished during this time period.

Respectfully submitted,

B. B. Mazanti
Project Director

BBM/c

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FINAL REPORT

GEORGIA TECH PROJECT NO. A-833
GHD RESEARCH PROJECT NO. 6503

A STUDY OF LIGHTWEIGHT AGGREGATE CONCRETE FOR PRESTRESSED
HIGHWAY BRIDGE GIRDERS - PHASE III

B. B. MAZANTI

Contract with

STATE HIGHWAY DEPARTMENT OF GEORGIA

In cooperation with

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF PUBLIC ROADS

March, 1968

1968



Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia

FINAL REPORT

GEORGIA TECH PROJECT NO. A-833
GHD RESEARCH PROJECT NO. 6503

A STUDY OF LIGHTWEIGHT AGGREGATE CONCRETE FOR
PRESTRESSED HIGHWAY BRIDGE GIRDERS - PHASE III

By

B. B. Mazanti
Professor of Civil Engineering

Contract with
STATE HIGHWAY DEPARTMENT OF GEORGIA
In cooperation with
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF PUBLIC ROADS

March, 1968

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the State Highway Department of Georgia or the Bureau of Public Roads.

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CHAPTER I

INTRODUCTION

A. Scope of the Study

The use of lightweight aggregates in prestressed concrete for bridge construction has been increasing, since such use is often advantageous due to the lower unit weight of the concrete. One of the major detriments to the proper use of lightweight aggregates in prestressed concrete is the variability of the shrinkage and creep characteristics of a given aggregate when contrasted with aggregates from another source or plant. Published data on these two characteristics show values ranging from less-than to several-times-greater-than corresponding values for normal weight concrete.

The workability of the lightweight concrete is usually poorer than comparable normal weight concrete. This has led to the use of a "semi-lightweight" concrete made with lightweight coarse aggregate and normal weight fine aggregate. The semi-lightweight concrete is, of course, intermediate in weight between an all lightweight mix and a normal weight mix but the workability is usually much better than the lightweight mix. The problem of not knowing correct creep and shrinkage coefficients for the semi-lightweight concrete is still to be contended with.

In Georgia, a good quality, expanded shale lightweight aggregate is produced by the Georgia Lightweight Aggregate Company at its Rockmart plant. Concrete made with this aggregate has been used in both ordinary reinforced concrete and in prestressed concrete members for private construction. Creep and shrinkage data were lacking however for both lightweight and semi-lightweight concrete made with this aggregate.

Since the inception of the project, an additional source of lightweight aggregate for concrete has become readily available to the Georgia market.

Consequently, although it is not a Georgia-produced material, this aggregate was included in the present testing program.

Descriptions of both lightweight aggregates are included in Chapter III.

As originally conceived, the overall program consisted of four phases, all of which were separate and distinct with respect to the included work but dependent upon the preceeding phases. This division was made so that the project could be terminated at the end of any phase and still produce a package of information having material value.

Phase I was concerned primarily with the mix design characteristics of the Georgia Lightweight Aggregate (Galite) as well as the shrinkage and creep characteristics under constant loading conditions. Equipment was designed and constructed for the creep tests. The results of Phase I were reported in "A Study of Lightweight Aggregate Concrete for Prestressed Highway Bridges", Final report - Phase I, by Billy B. Mazanti and James R. Fincher, January 1, 1959-March 1, 1962. The results of Phase I showed that the Galite was capable of producing consistent, satisfactory concrete. The shrinkage of the lightweight concrete was shown to be approximately equal to that of normal weight concrete under simulated "Field conditions", i.e., 70°F and 50 percent humidity; however, the creep strain of the lightweight concrete was significantly greater than that of the normal weight concrete under the same environmental conditions. In addition, the creep strain was shown to be a linear function of the ratio of applied stress to the strength at time of loading.

Phase II was concerned primarily with the relation between creep strains in prestressed beams and creep strains of sustained-loaded specimens. The results of this work showed that fairly good correlation exists between the creep coefficient for prestressed cylinders and for prestressed beams. Attempts

to predict the creep strain behavior of prestressed beams utilizing data from constant-loaded cylinders was unsuccessful.

Phase III was initiated to determine for semi-lightweight concrete, some of the characteristics studied for all lightweight concrete in Phases I and II. In addition, the present work was expected to provide data regarding the behavior of full sized bridge members with respect to creep, shrinkage and loss-of-prestress and the correlation between the full sized members and laboratory sized prestressed beams.

Finally, Phase IV, if initiated, would include the instrumentation and monitoring of bridges constructed of the semi-lightweight concrete. Correlation of the in-service behavior with the design criteria would follow.

B. Study Procedure

In order to accomplish the desired results, the following general procedure was established:

1. Review and check the original semi-lightweight concrete mix designs used in Phase I and Phase II.
2. Check and extend creep data for semi-lightweight concrete cylinders under conditions of constant compressive stress.
3. Study creep characteristics of semi-lightweight concrete cylinders under "prestress" conditions.
4. Study creep characteristics of laboratory sized, semi-lightweight concrete prestressed beams.
5. Instrument and study actual bridge members for analysis of their in-use performance with respect to creep, shrinkage, and loss-of-prestress.
6. Correlation of "laboratory creep, shrinkage and loss-of-prestress" with the performance of the full sized member.

C. Report Contents

The equipment, instrumentation and testing techniques used in this study are included in CHAPTER II. Of particular interest to researchers studying concrete creep will be the hydraulic pressure maintaining system and the loss-of-prestress beam test stands.

CHAPTER III deals with the materials used in the prestressed elements. Properties of the two lightweight aggregates are included as well as the mix design and batching procedures.

The test program and the results therefrom are in CHAPTER IV. The significance of the results is discussed under the various headings, e.g. Shrinkage tests, and a summary of the results and conclusions is presented in CHAPTER V. CHAPTER VI contains recommendations based on the results of this work and indicates some areas of interest for further study.

CHAPTER II

LABORATORY EQUIPMENT AND INSTRUMENTATION

Special equipment and instrumentation used in the laboratory studies is described in this chapter. Some of the equipment and instrumentation was utilized in Phases I and II and has been described in previous reports, however, more-or-less complete details are presented herein for ready reference.

A. Concrete Cylinder Molds

The cylinder molds are of heavy gage cold drawn seamless steel tubing, split longitudinally and bored to 6.00 inches inside diameter. Originally, the molds were drilled 1 inch from the top and the bottom to provide locating holes for stainless steel inserts. These holes were in pairs spaced around the mold on 120° centers and the inserts, which were cast into the fresh concrete, served to attach external gage points for measuring deformations. For the present series of tests, another method of gage point application was used (as will be later described) and, as a consequence, the drilled holes in the molds were sealed.

The mold bases are $1\frac{1}{2}$ inch thick steel with a $\frac{3}{8}$ inch deep groove milled to accommodate the steel cylinder molds. Set screws hold the molds in place. The bases provide sufficient mass to allow the use of an external electric vibrator for compacting the specimens. In addition, a flat end, perpendicular to the cylinder's long axis, is assured. The molds produce standard 6 inch diameter by 12 inch long specimens.

A special "cap" is used as a means of attaching a standard electric laboratory vibrator to the cylinder mold. Figure 1 shows the essential features of the mold, base plate, and cap.

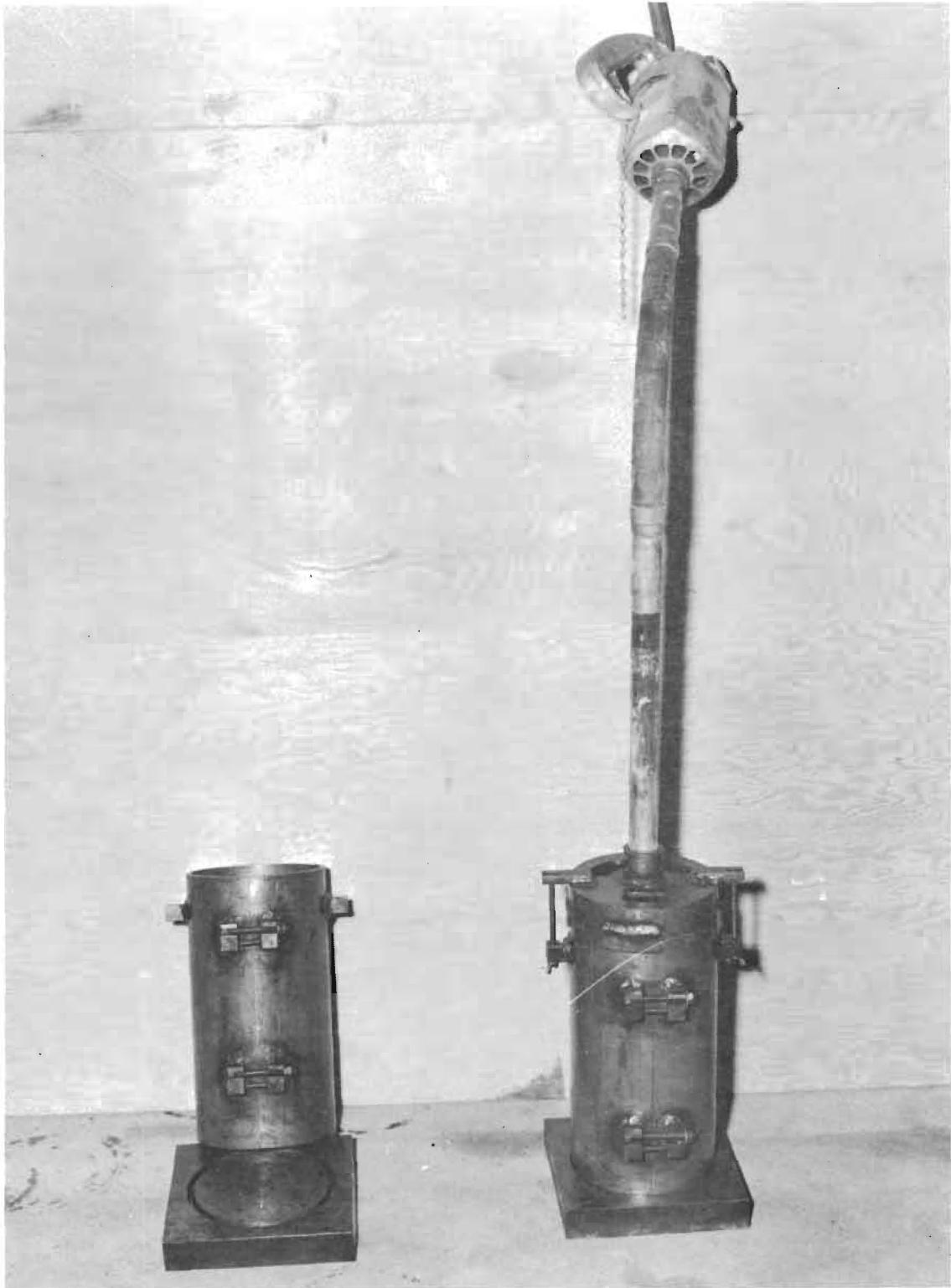


Figure 1. Cylinder Mold.

The cylinder molds were modified slightly when used for casting the hollow cylinders to prestress. To produce the hole through the specimens, a slightly-tapered steel rod with a diameter of $1\frac{1}{4}$ inch was placed in a socket drilled in the mold base.

B. Static-Load Creep Test Frames

The loading frame assemblies are of steel, consisting of a table, or bench made up of three sets of three each, high strength, $1\frac{1}{4}$ inch diameter steel rods spaced to accommodate the hydraulic load cells (to be described later) and supporting three individual top plates. The top plates furnish reactions for the loads applied to the cylindrical concrete specimens by the hydraulic load cells. Figure 2 shows the essential features of the loading frame assemblies as well as the pressure controller described later.

C. Hydraulic Load Cells

Three sizes of hydraulic load cells were constructed. The design of the cells are essentially that described by Best, et al.⁽¹⁾ In order to reduce corrosion under long term exposure to high humidities, all cylinders and and piston plates were cadmium plated. The piston sized and areas are as follows:

<u>Nominal Size</u> (Inches)	<u>Diameter</u> (Inches)	<u>Area</u> (Square Inches)
9	9.015	63.83
8	8.015	50.45
$6\frac{1}{2}$	6.515	33.34

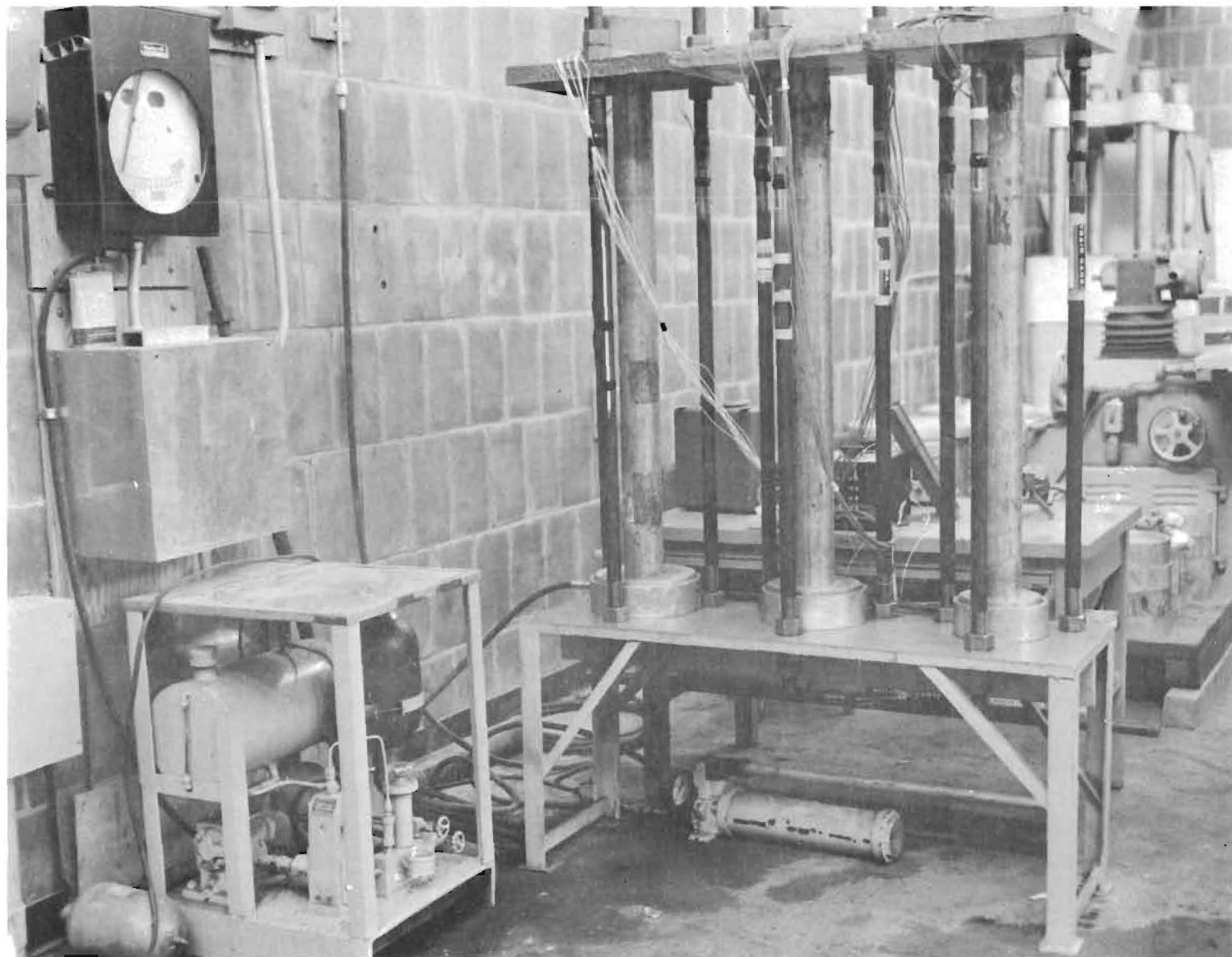


Figure 2. Loading Frame Assembly.

Molded rubber piston cups (Johns-Manville style 401) were used as oil seals. These cups are subject to slight leakage under hydraulic fluid pressures of 1500 psi which tends to reduce the friction between the cup and the cylinder wall and to allow the full hydraulic force to be transmitted to the specimens. Figure 3 shows the essential details of the cells.

D. Hydraulic Pressure Maintaining System

The hydraulic pressure maintaining system is similar to that described in "Loading System for Creep Studies of Concrete," by Best, Pirtz and Polinka. The system consists essentially of a hydraulic oil reservoir, fuel-injection pump operated by an electric motor, hydraulic accumulator and a pressure controller. Figure 4 shows a schematic of the hydraulic pump and control unit and a list of the parts used.

This pressure system was used for the constant-load tests on the cylindrical specimens.

E. Prestressing Elements

Both solid bars and strands were utilized as prestressing elements in the various test set-ups in the laboratory.

The solid bars were used for prestressing the hollow cylinders and consisted of "Regular Grade" Stressteel bars 1-1/8 inch in diameter. The properties of this material, based on tensile tests, are as follows:

Tensile strength	160,200 psi
Yield strength (0.2% offset)	138,500 psi
Proportional limit	78,450 psi
Modulus of elasticity	27×10^6 psi

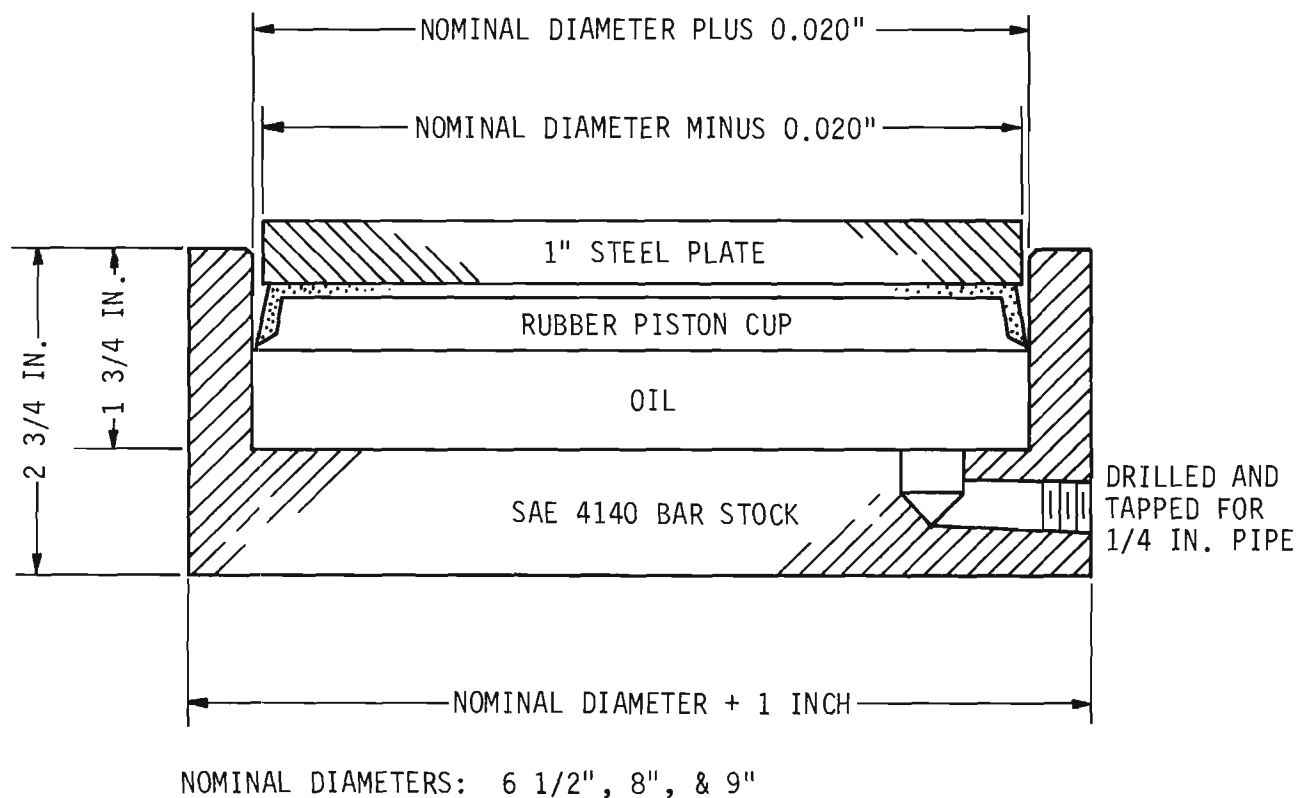
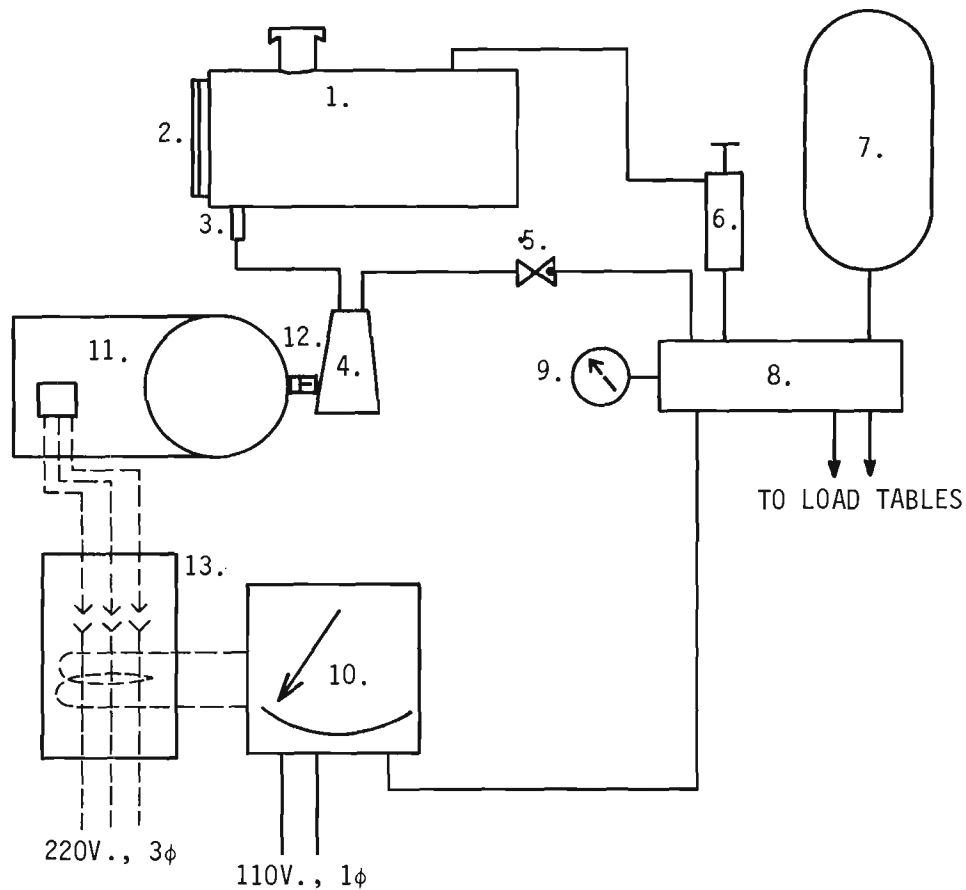


Figure 3. Hydraulic Load Cells.



1. RESERVOIR, VENT TO ATMOSPHERE
2. VISUAL OIL LEVEL GAGE
3. STRAINER
4. AMERICAN-BOSCH FUEL INJECTION PUMP-APE IB90P 300/3
5. VICKERS IN-LINE CHECK VALVE, 1/4 PIPE SIZE MODEL NO. DT 8PI-02-68-10
6. VICKERS REMOTE CONTROL PRESSURE RELIEF VALVE MODEL NO. C-175-F-10
7. GREER 1 GALLON, 30A-1A HYDRAULIC ACCUMULATOR, 3000 psi SERIES, NITROGEN CHARGED
8. MANIFOLD
9. PRESSURE GAGE
10. MINNEAPOLIS-HONEYWELL, ELECTROVANE PRESSURE CONTROLLER, INDICATING TYPE, 1250-2500 psi, MODEL MH 704 CIP2-23 III IV H
11. BOSTON GEAR RATIOMOTOR NO. M 115-30 EW WITH 1/3 HP, 220 V, 3 ϕ ELECTRIC MOTOR
12. BOSTON GEAR COUPLING FC BB 15
13. MAGNETIC HOLDING COIL, 3 POLE, NORMALLY OPEN, 30 AMP SWITCH

Figure 4. Hydraulic Pressure Controller.

% Elongation, 2" gage	24.5
% Elongation, 8" gage	9.5
% Red. of Area	34.3

The Stressteel bars were threaded both ends and regular Stressteel nuts were used. Bearing plates for the cylindrical specimens were 6 inch square, 1-3/4 inch thick structural grade steel.

The strand used for laboratory prestressing was 7-wire ASTM Grade produced by Florida Wire and Cable Company, Jacksonville, Florida. These strands were utilized in the Stress Transfer studies and in the Loss of Prestress studies.

F. Loss-of-Prestress Beam Test Stands

The Prestress Loss Frame is basically the same as described by Hanson.⁽²⁾ A diagrammatic sketch of this equipment is shown in Figure 5.

Eccentric prestressing is accomplished by the proper positioning of the concrete prisms so that the load is applied at the one-third point of the cross-section.

As pointed out by Hanson, the use of this arrangement eliminates or materially reduces several potential sources of error in residual load measurement in loss of prestress studies. Most important among these were:

1. Slip of the strand grips after initial loading.
2. Steel relaxation with time.

These items were essentially eliminated from consideration by pre-conditioning the frames with a 25 to 30% overload using aluminum bars as dummy

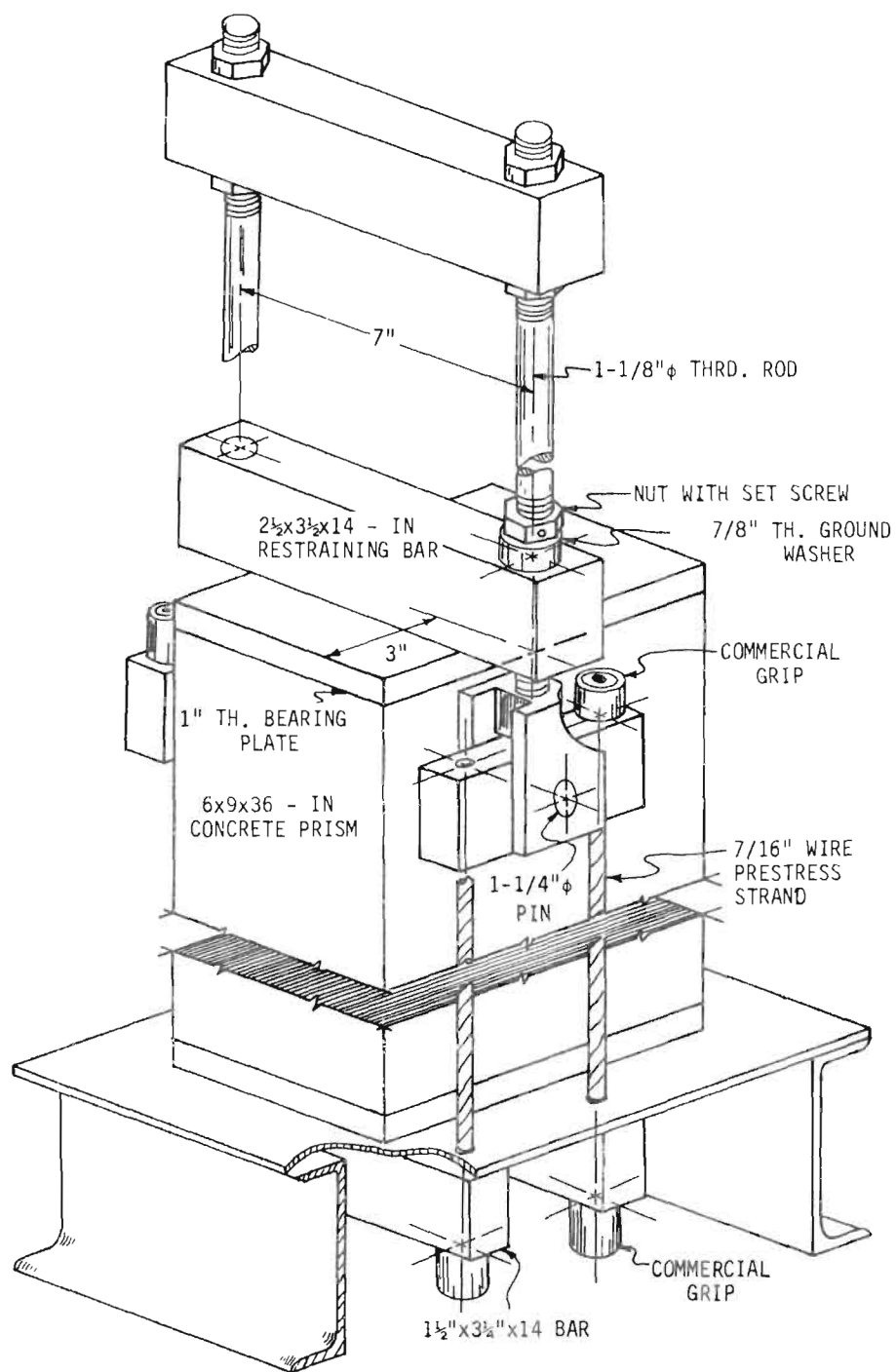


Figure 5. Prestress Loss Test Frame.

compression members. In this way, the grips were firmly anchored and the steel relaxation effects were removed due to maintaining the preload for approximately 2 hours prior to loading the test specimens.

Changes in prestress were measured by means of SR-4 strain gages mounted on each of the four prestress strands and periodically taking readings.

G. Gage Points for Deformation Measurements

External gage points were attached to all laboratory specimens for the determination of deformation under the applied loads. The gage points were cubical, made of stainless steel or hard-brass bar stock with dimensions of approximately $\frac{1}{4}$ inch. A hole was drilled in one face to a depth sufficient to accomodate a standard Whittemore gage. The gage points were cemented to the specimens with a quick-setting, non-shrink grout by drilling the concrete to a depth of one-quarter inch, filling the cavity with the grout and embedding the gage point into the grout. This procedure was utilized after considerable experimentation which indicated that more reliable results were possible by this method of attachment.

The particular arrangement and location of the gage points on the specimens was determined by the test being conducted and will be indicated in appropriate sections of this report.

CHAPTER III

MATERIALS, MIX DESIGN AND TEST SPECIMENS

A. Cement

Cement used in the project was Penn-Dixie, Type III (High Early Strength) Portland.

B. Lightweight Aggregates

The lightweight aggregate used in the tests came from two sources.

Galite Lightweight Aggregate

One aggregate is an expanded shale material which is manufactured by the Georgia Lightweight Aggregate Company, Rockmart, Georgia. The aggregate is normally supplied in three sizes: fine (No. 4 to 0), intermediate ($3/8$ inch to No. 8) and coarse ($3/4$ inch to No. 4). Since only semi-lightweight mixes were used in this work, only the coarse aggregate was lightweight material. Typical gradation of this material (as supplied) is as follows:

Galite Lightweight Coarse Aggregate

<u>Sieve Size</u>	<u>% Passing by Wt.</u>
$3/4$ inch	100
$1/2$ inch	73.7
$3/8$ inch	44.3
No. 4	4.0
No. 8	3.2
No. 16	2.4

The aggregate had the following characteristics:

Unit Wt. (Dry, Rodded)	53.6 pcf
Absorption	8.0 %
Specific Gravity	
Apparent	1.75
Bulk (S.S.D.)	1.65
Bulk (Dry)	1.54

Clinchlite Lightweight Aggregate

The other lightweight aggregate used in this study was furnished by the Clinchfield Coal Company, Dante, Virginia. This material, while not a locally produced aggregate, is readily available to the Georgia market and, as a consequence, was included in the project. It is an expanded shale lightweight aggregate produced by the rotary kiln process.

From the normally available sizes, fine (3/16 inch to 0), intermediate (3/8 inch to 3/16 inch) and coarse (3/4 inch to 3/16 inch), the coarse was used in this study. Typical gradation of this material (as supplied) is as follows:

<u>Clinchlite Lightweight Coarse Aggregate</u>	
<u>Sieve Size</u>	<u>% Passing by Wt.</u>
3/4 inch	91.8
1/2 inch	54.5
3/8 inch	24.9
No. 4	3.6
No. 8	2.9
No. 16	2.5

The aggregate had the following characteristics:

Unit Wt. (Dry, Rodded)	57.8 pcf
Absorption	9.4 %
Specific Gravity	
Apparent	1.88
Bulk (S.S.D.)	1.75
Bulk (Dry)	1.60

C. Fine Aggregate

Fine aggregate used in all laboratory mixed concrete was a natural river sand as supplied by the Atlanta Sand and Supply Company. This sand

meets the current specification requirements of the State Highway Department of Georgia for gradation of fine aggregates for Portland cement concrete, size No. 10. A sieve analysis of this material is as follows:

<u>Sieve Size</u>	<u>% Passing</u>
3/8 inch	100
No. 4	100
8	99
16	89
30	57
50	18
100	3

The aggregate had the following characteristics:

Unit Wt. (Dry, Rodded)	99.3 pcf
Absorption	0.8 %
Specific Gravity	
Apparent	2.46
Bulk (S.S.D.)	2.42
Bulk (Dry)	2.39

D. Mix Design, Semi-lightweight Concrete

In prior work on this project, concrete mix design had been based on accepted methods and trial mixing with re-proportioning for best work ability. It was decided that a more realistic approach would be to seek the advice of the industry with respect to mix designs which were "workable" under the conditions in which the concrete would be used. Consequently, mix designs were utilized as supplied by the respective lightweight aggregate manufacturers. The following basic mixes were used:

1. Galite Lightweight Aggregate Mix

Cement	677 lb.
Water	425 lb.
Coarse Agg. (Galite)	950 lb.
Fine Agg. (Sand)	1170 lb.
Retarder (Retardwell)	14 oz.

2. Clinchlite Lightweight Aggregate Mix

Cement	658 lb.
Water	417 lb.
Coarse Agg. (Clinchlite)	1188 lb.
Fine Agg. (Sand)	1148 lb.
Retarder (Retardwell)	14 oz.

(All weights are based on an oven dry basis and are for a cubic yard of concrete.)

The Compressive Strength-Age relation for these two mixes are shown in Figures 6 and 7. The gain in strength with age is very close to the same for both of the two concrete mixes. It should be noted, however, that the Galite mix has a slightly higher cement content than does the Clinchlite mix.

The static Modulus of Elasticity of the two mixes is as follows:

Mix	Secant Modulus @ 50% f'_c		
	<u>3 day</u>	<u>5 day</u>	<u>7 day</u>
Galite	3.04	3.25	3.68×10^6 psi
Clinchlite	3.06	3.60	4.16×10^6 psi

E. Batching Procedure

The batching procedure for the concrete consisted of the following:

1. Premix all aggregate and approximately 90 percent of the water for 20 minutes in the mixer drum.

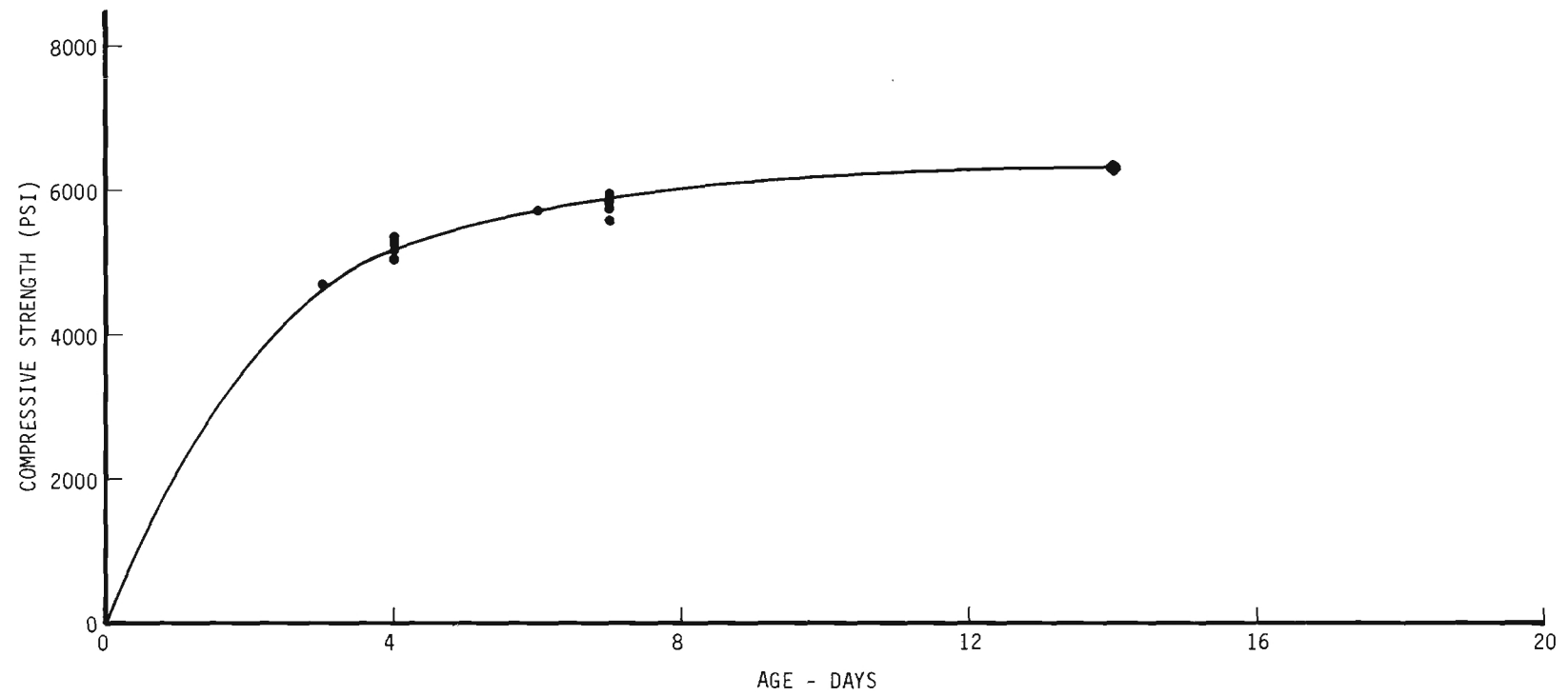


Figure 6. Strength-age Relation, Galite Semi-lightweight Concrete.

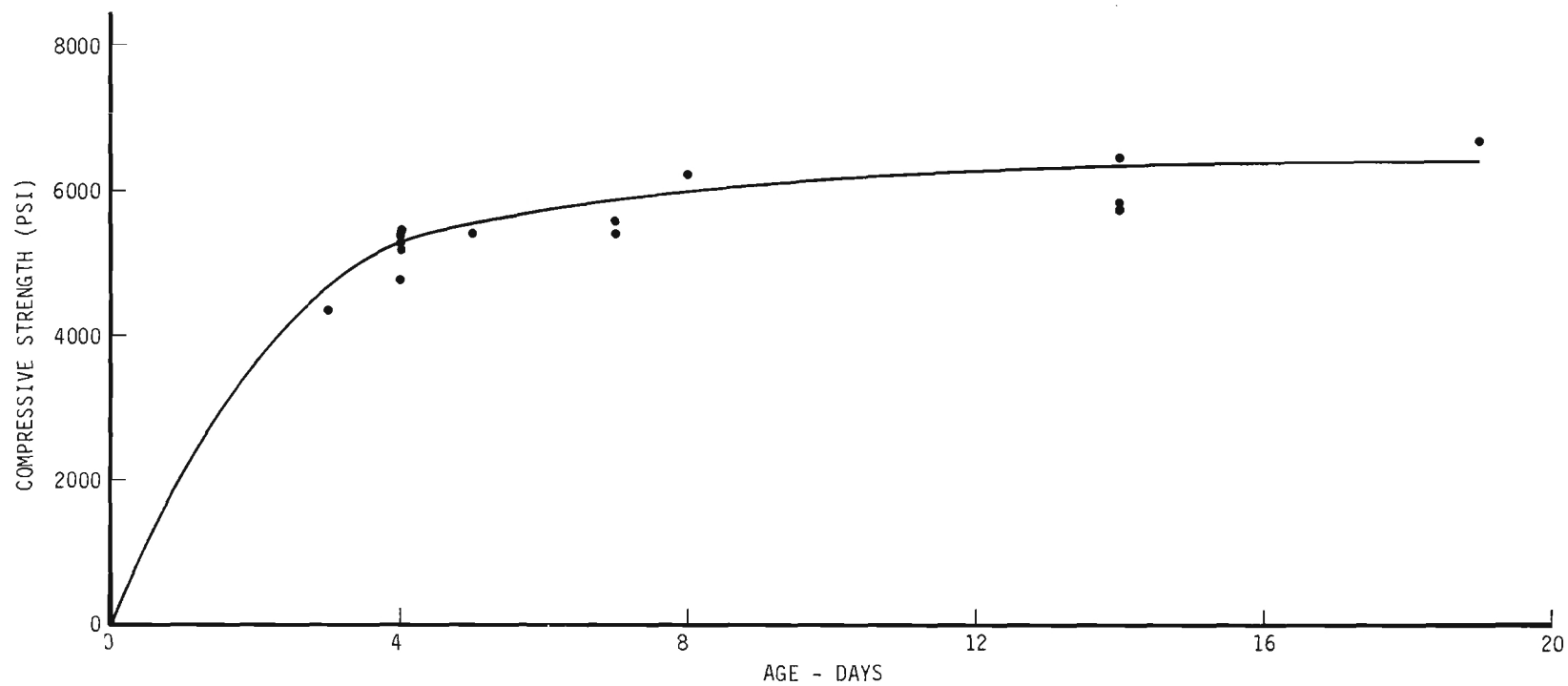


Figure 7. Strength-age Relation, Clinchlite Semi-lightweight concrete.

2. All cement added and mixing continued for 5 minutes.
3. Slump controlled between 2 to $2\frac{1}{2}$ inches by the addition of all or part of the 10 percent water withheld.

F. Test Specimens

In the laboratory testing program, the following types of specimens were utilized:

1. Strength specimens.
2. Cylindrical creep and shrinkage specimens.
3. Rectangular beams for Loss-of-Prestress and for Stress-Transfer.

Cylindrical Specimens.

All strength, cylindrical creep and shrinkage specimens were cast in the special molds previously described in this report. The casting procedure generally followed ASTM C192-57 except that external vibration was utilized by means of the special mold caps. A Mall electric concrete vibrator, Model 1EV was used for all vibration purposes in the laboratory. The cylinders were vibrated, after being filled and rodded, for 5 seconds for each specimen.

Following the casting operations, heavy plastic sheet was used to cover each specimen in order to prevent excessive moisture evaporation. At an age of approximately 24 hours, the specimens were removed from the molds, and then placed in a 100 percent humidity, 70°F curing room until time for testing.

Rectangular Beams

Rectangular beams were of two types. Those for the Loss-of-Prestress studies were 6 in. x 9 in. x $\frac{3}{4}$ in. They were cast in heavy-plywood forms, reinforced to minimize deformation during the casting and hardening stages.

The forms were filled with concrete in three layers, each layer being well-rodded. The concrete, after filling of the forms was complete, was vibrated in a manner which simulated that usually accomplished in the field. After completion of the casting operations, the beams were covered with heavy plastic sheet for 24 hours and then removed from the forms and placed in the curing room.

The beams for the Stress Transfer study were cast in metal forms. The forms consisted of 2 in. x 4 in. steel channels as side pieces with 1/4 in. steel plate bottoms. The forms were securely clamped to a metal vibrating table and the prestressing strand was passed through 2 inch thick steel end blocks which served to locate the strand centrally within the form. A "header" was placed approximately 1 foot from one end of the beam forms in order to leave exposed a length of strand which served as a prestress-force dynamometer. SR-4 strain gages were mounted on the prestressing strands and then calibrated prior to the use of the strands in the beams. The proper prestress force was applied to the strand by means of a Simplex prestress hydraulic ram and the prestress load was monitored by both the hydraulic pressure in the ram and the strain gages on the strand. The prestress load was maintained for a period of 24 hours prior to the pouring of the concrete. The concrete was poured in the beam forms in two layers. The form was filled to slightly above the prestressing strand, spaded and rodded, then vibrated for 10 seconds. The top layer was similarly placed. The beam was covered with heavy plastic after being struck-off level. After 24 hours, the plastic was removed, the beams were covered with burlap and the burlap kept wet until time for testing.

CHAPTER IV

TEST PROGRAM AND RESULTS

A. Shrinkage Tests

The shrinkage characteristics of both the Galite Semi-Lightweight concrete and the Clinchlite Semi-Lightweight concrete was determined from tests on cylindrical specimens which were not subject to loading. The specimens were each instrumented with three sets of gage points mounted at 120° intervals around the circumference of the cylinders. Nominal gage lengths of 10 inches were used. The deformation of the specimens was measured by means of a 10 inch gage length, Whittemore gage. This is a hand-held, mechanical type extensometer-compressometer allowing direct reading of deformations. Dial indicator divisions are in 0.0001 inch which allows interpolation to at least 0.00005 inch and for a nominal 10 inch gage length, strains on the order of 5×10^{-6} inches per inch can be determined.

Since it was desired to approximate "in-practice" conditions, the shrinkage and the creep testing was accomplished in a constant-environment room where the temperature was maintained at 70°F and the relative humidity kept at 50 percent.

Shrinkage was determined for both mixes with respect to varying times of 100 percent humidity curing prior to storage at the test environment. The results of these tests are presented graphically in Figures 8 through 11 in the form of Shrinkage vs. Time curves as both arithmetic and semi-logarithmic plots.

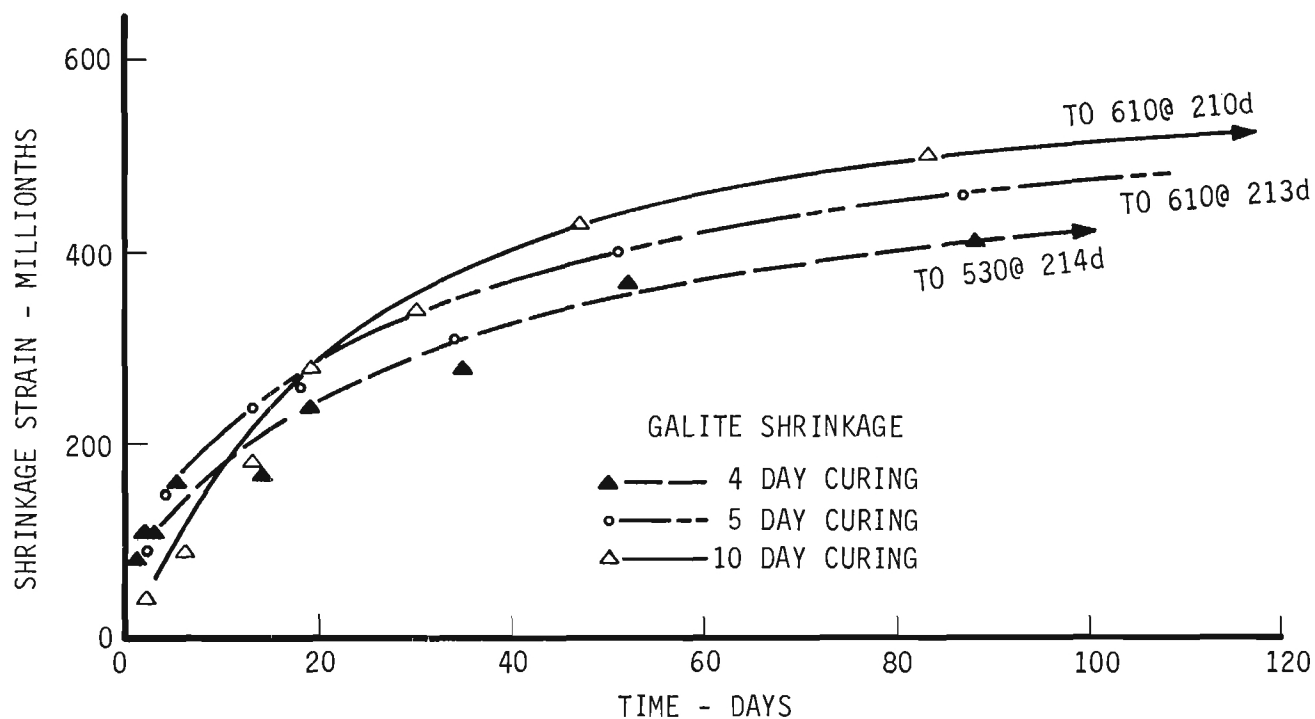


Figure 8. Shrinkage of Galite Semi-lightweight Concrete for Various Ages of Curing, Arithmetic Plot.

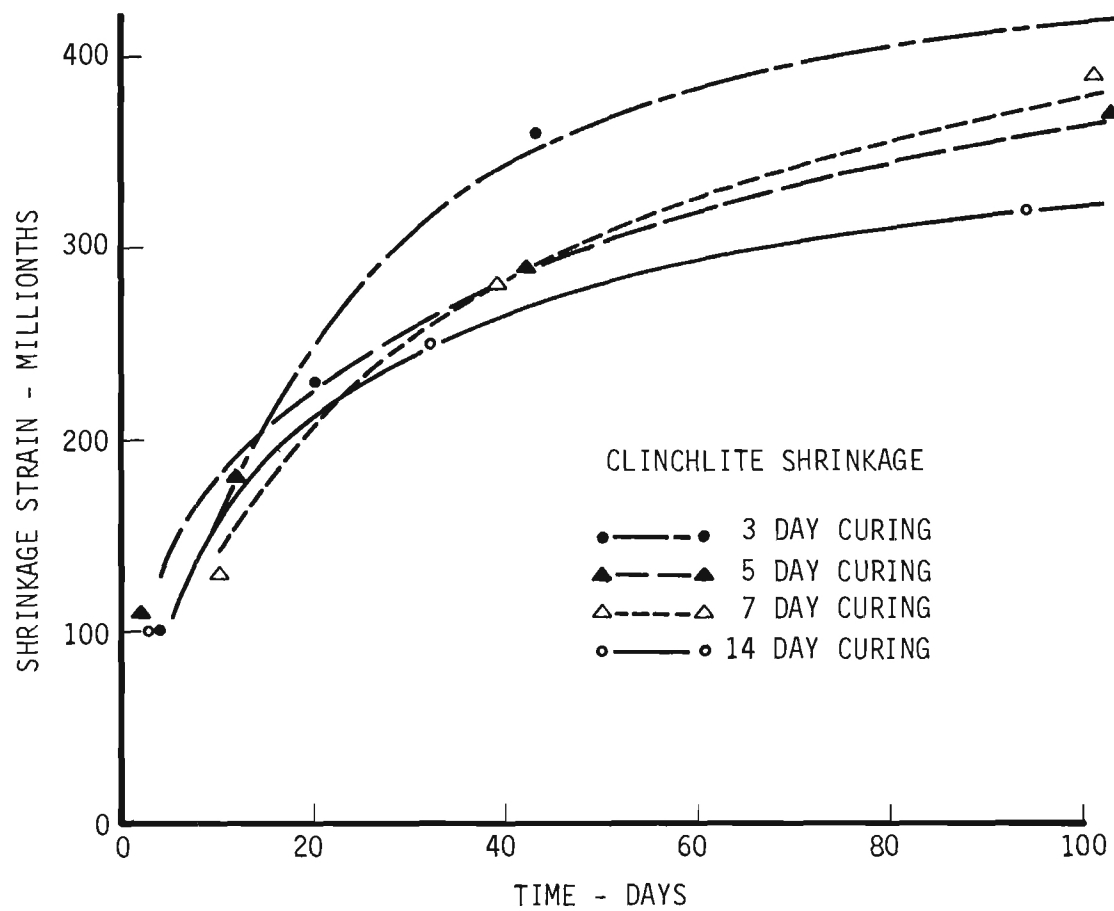


Figure 9. Shrinkage of Clinchlite Semi-lightweight Concrete for Various Ages of Curing, Arithmetic Plot.

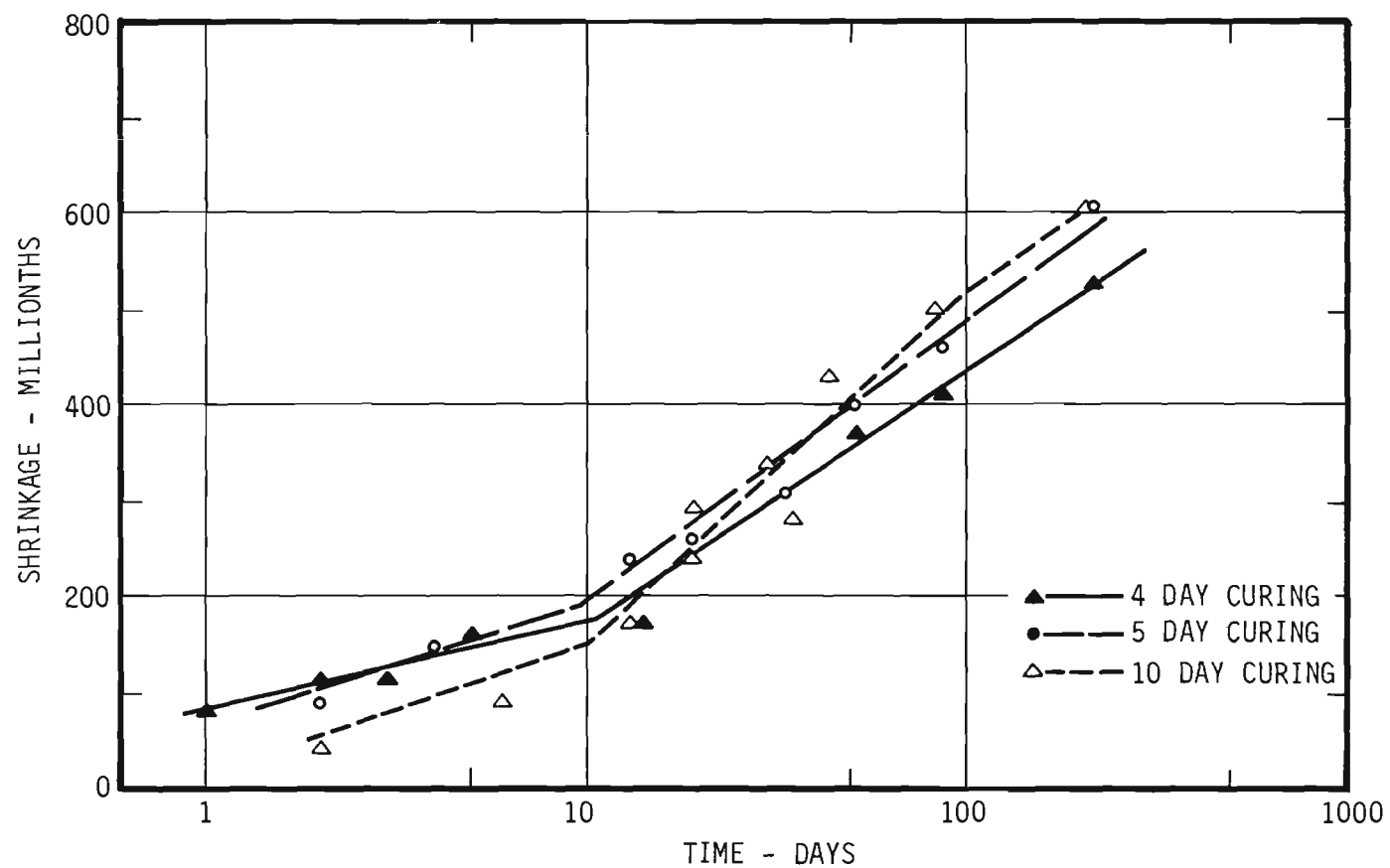


Figure 10. Shrinkage of Galite Semi-lightweight Concrete for Various Ages of Curing, Semi-log Plot.

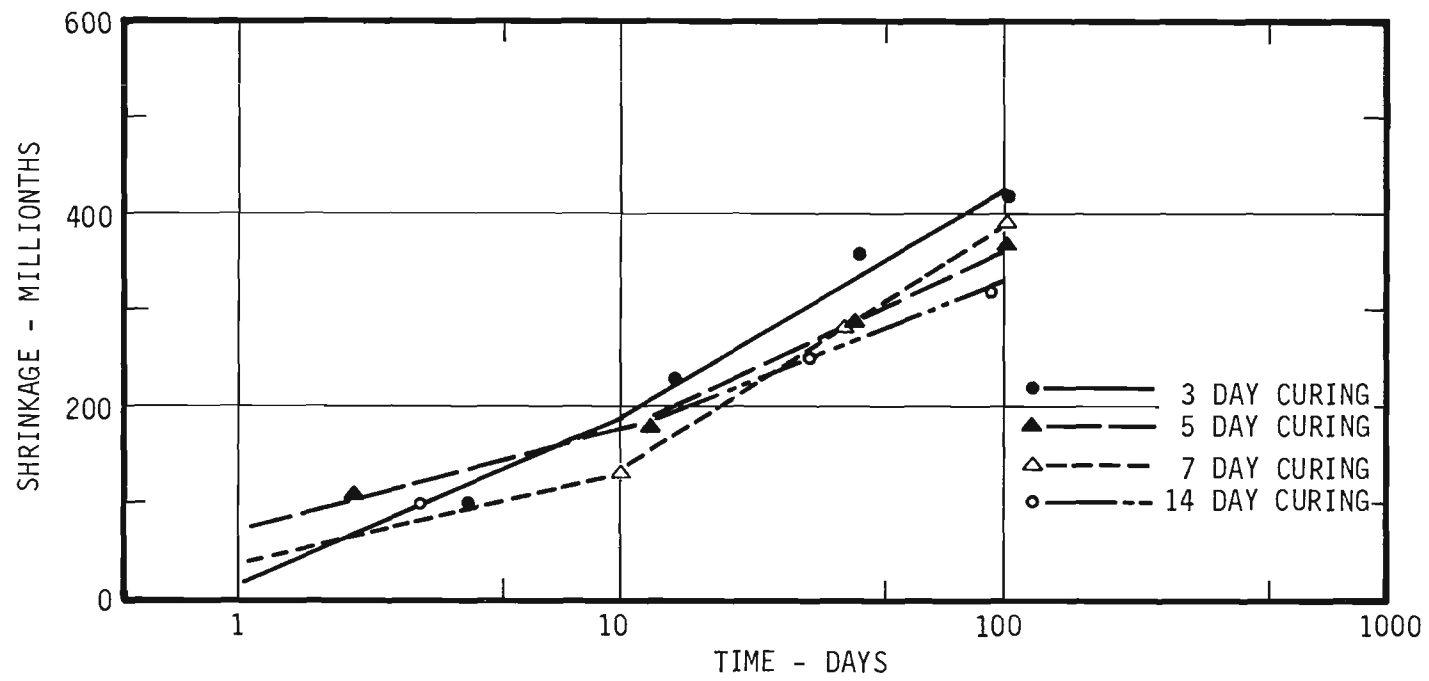


Figure 11. Shrinkage of Clinchlite Semi-lightweight Concrete for Various Ages of Curing, Semi-log Plot.

Shrinkage of the Galite concrete was also determined by the use of a rectangular beam 6 in. x 9 in. x 36 in. This was in connection with the Loss-of-Prestress studies to be described later. The results of this test are shown in Figures 12 and 13.

Results and Conclusions of Shrinkage Tests

The shrinkage of the semi-lightweight concretes follows a trend which is typical of concrete in general. The rate of shrinkage is a maximum at early ages and continuously decreases with increasing time. On semilogarithmic plots, the shrinkage curves appear to follow either straight lines or a series of straight lines.

The effect of time of moist curing prior to storage in the 50 percent relative humidity environment is not clearly defined. In the case of the Galite concrete, there was apparently an increase in the amount of drying shrinkage for the cylinders which were cured longer. This is contrary to what could be considered normal since the concrete should gain strength with increased curing times and, as a consequence, its resistance to shrinkage should decrease.

The shrinkage of the Clinchlite concrete followed a trend more in accordance with what would be expected, in that the shrinkage tended to decrease with increasing time of moist curing.

These results indicate that while there should be, and probably is, a lesser net shrinkage of the concrete with increasing curing times, the amount of the decrease is not significant when compared to the total shrinkage of concrete cured a minimum of 3 days. Variations of composition as well as variations of dimensions of actual prestressed members would probably be of

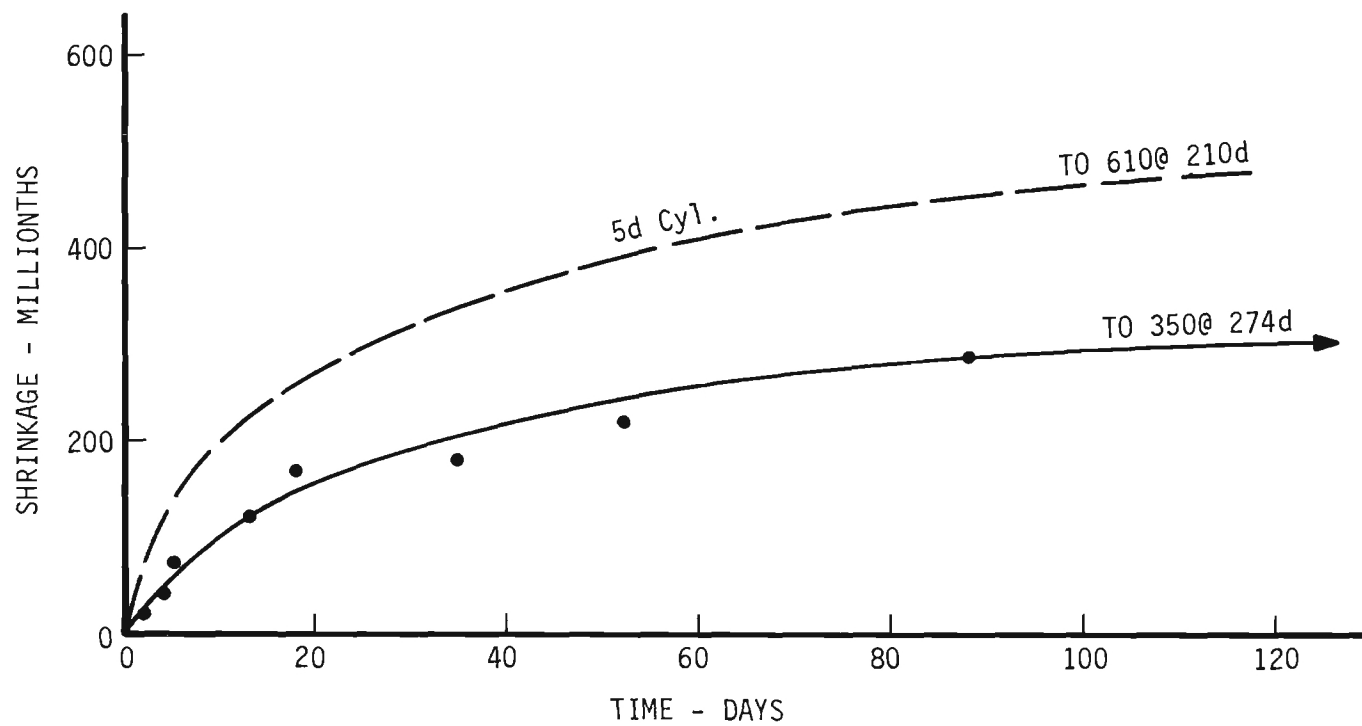


Figure 12. Shrinkage of Galite Semi-lightweight Concrete Beam, Arithmetic Plot.

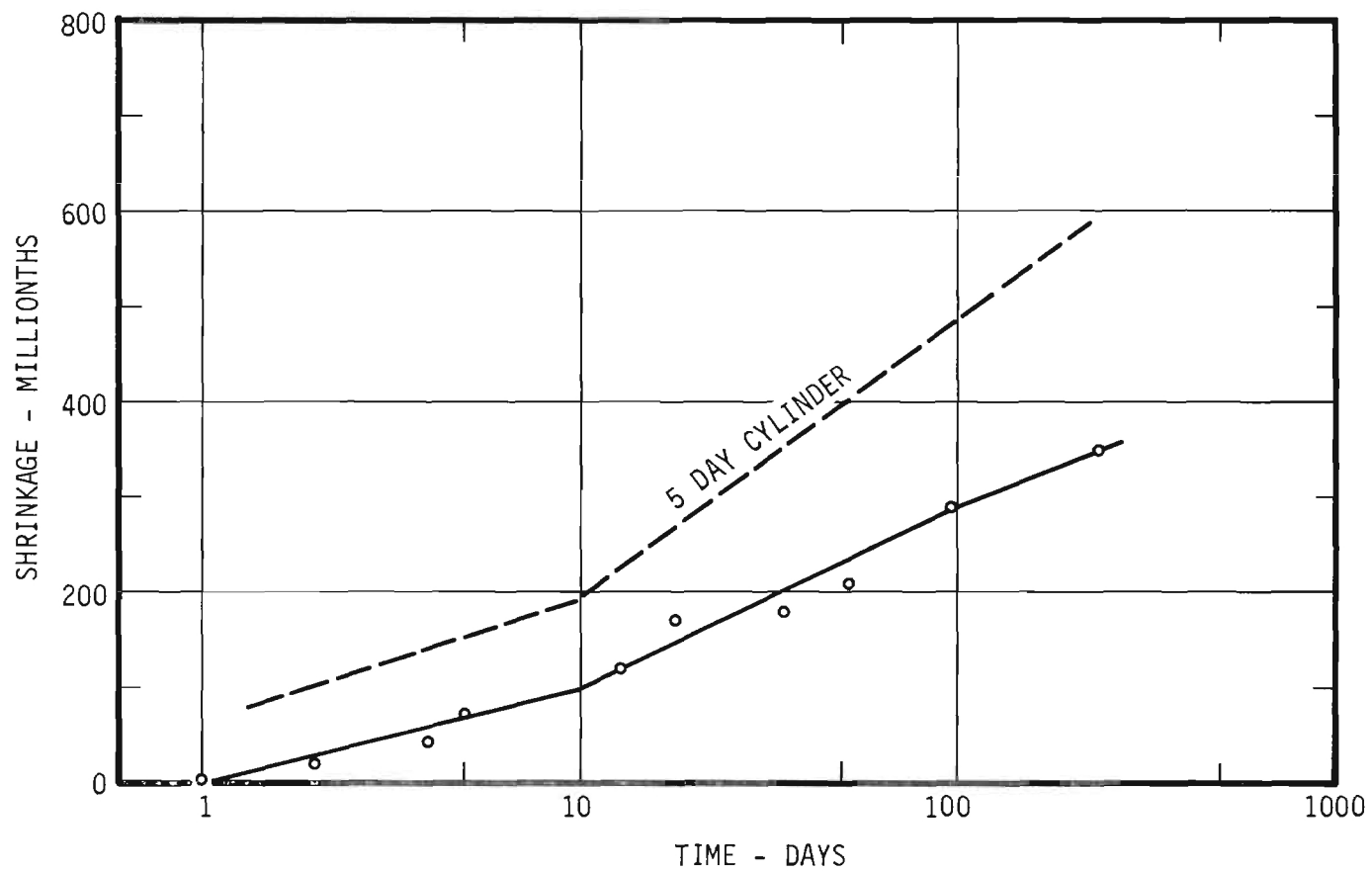


Figure 13. Shrinkage of Galite Semi-lightweight Concrete Beam, Semi-log Plot.

as much importance and would preclude the practicality of allowing for a reduction in shrinkage calculations. In addition, the extra construction time of the prestressed member would probably more than offset any advantages of the reduction in shrinkage.

Final values of shrinkage (as well as for creep) of the concrete can be calculated on the basis of hyperbolic equations of the following type:

$$\epsilon_s = \frac{(\epsilon_{s\infty}) t}{N_s + t}$$

where: ϵ_s = shrinkage strain at time t
 $\epsilon_{s\infty}$ = final shrinkage strain
 N_s = constant (time at which the shrinkage strain = $\frac{1}{2}$ final value)

For the Galite concrete, the following values may be used:

$\epsilon_{s\infty}$ = 790 millionths
 N_s = 62 days

For the Clinchlite concrete, the following values may be used:

$\epsilon_{s\infty}$ = 530 millionths
 N_s = 36 days

The effect of member size on shrinkage is indicated by Figure 12 and Figure 13. The shrinkage of the cylindrical specimens are contrasted with that of the 6 in. x 9 in. x 36 in. beam. It is evident that the member with the greater size has an appreciably less total shrinkage. The decrease is more than would be estimated on the basis of previous studies by Hanson and Mattock⁽³⁾ wherein a decrease in shrinkage of about 11 percent is indicated

for the relative shapes and sizes used here. As a consequence, it is not recommended here that a reduction in shrinkage for prestressed members be based on this data. The comparison is made as a matter of interest only, while the beam shrinkage was intended for specific use in the Loss-of-Prestress study.

B. Static Load Creep Tests

The creep characteristics of both the Galite Semi-Lightweight concrete and the Clinchlite Semi-Lightweight concrete were determined by testing solid, cylindrical specimens under constant loads of different magnitudes. The specimens were instrumented with gage points in the same manner as the creep specimens and the total deformations of the specimens were measured at various time intervals after loading. The shrinkage of the specimens was determined from companion specimens and the creep was calculated as the difference between the total deformation and the shrinkage.

In the earlier phases of this project, three different stress levels were imposed on the concrete mixes. Such was the intention in this test program also; however, it was found impossible to load the specimens with the largest-area cell without failure of the cylinders occurring, either at the time of loading or at some later time, shortly after loading. Due to such failures, several other test series were disrupted and, in order to prevent further loss, later tests were restricted to two different stress levels. These applied stress levels were 1650 psi and 2550 psi. The results of these tests are presented graphically in the form of Creep vs. Time curves and summarized in plots of Creep vs. Ratio of Applied Stress to Strength at Time of Loading. Figures 14 through 18 show these results.

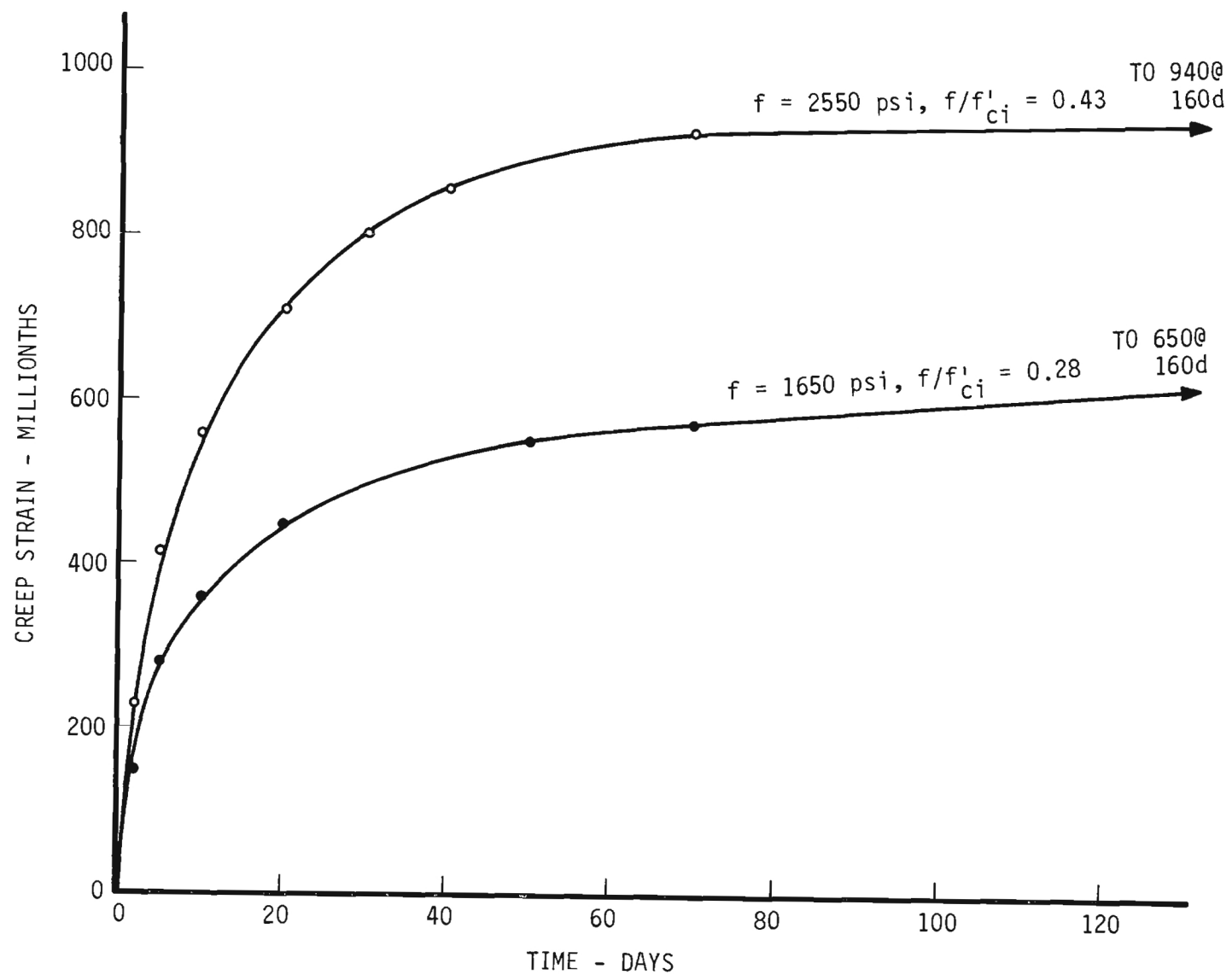


Figure 14. Creep Strain of Galite Semi-lightweight Concrete, Arithmetic Plot.

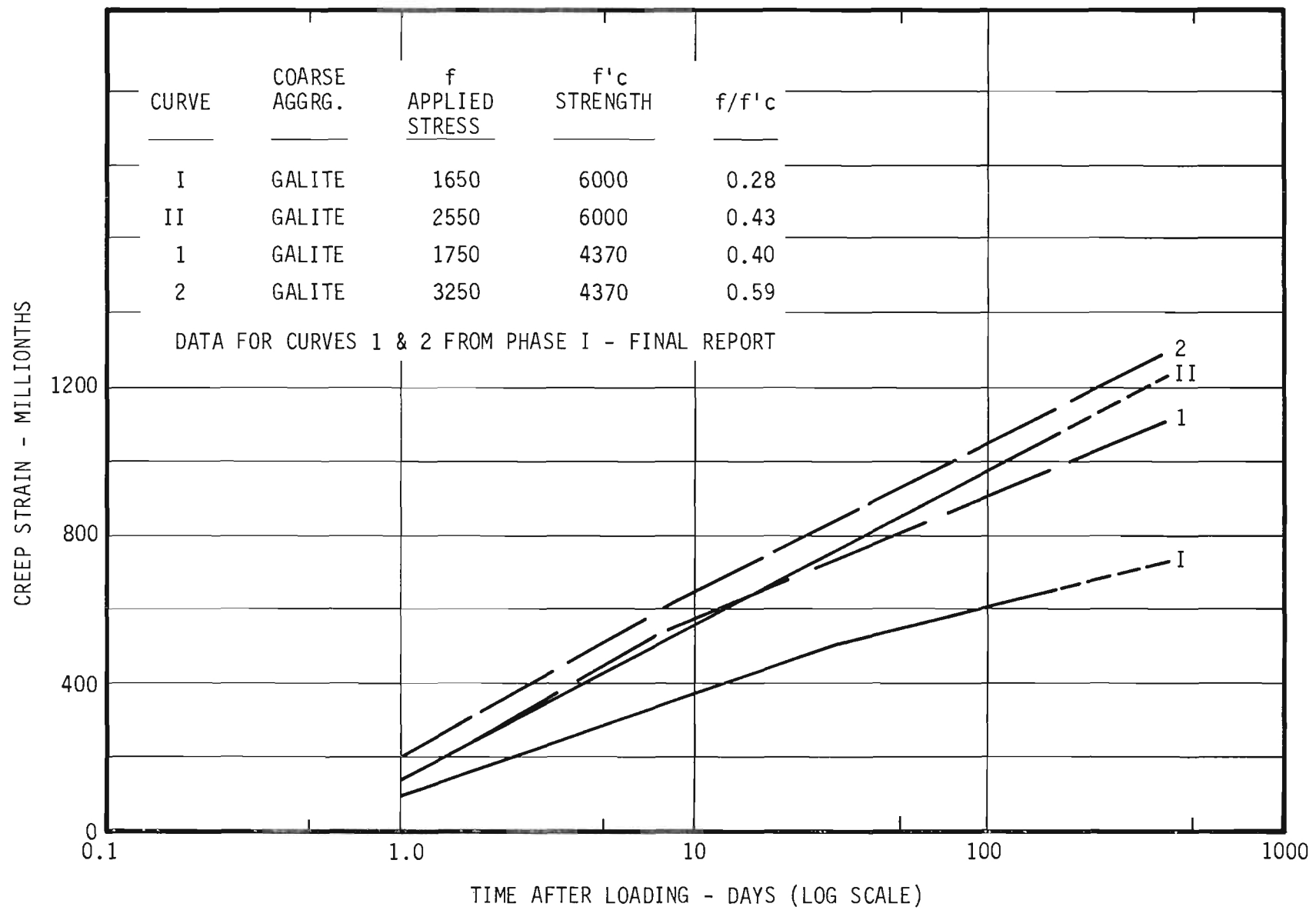


Figure 15. Creep Strain of Galite Semi-lightweight Concrete, Semi-log Plot.

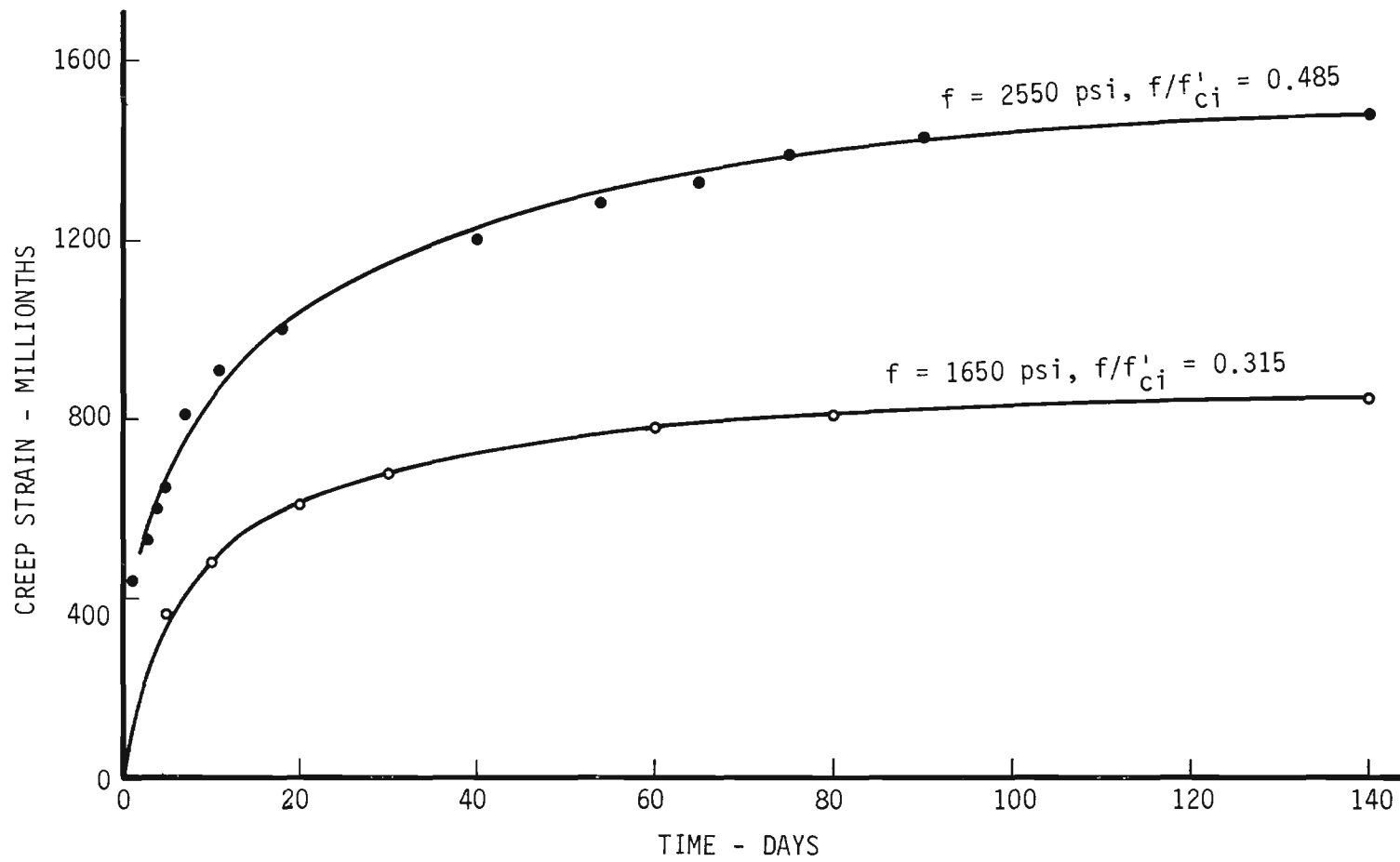


Figure 16. Creep Strain of Clinchlite Semi-lightweight Concrete, Arithmetic Plot.

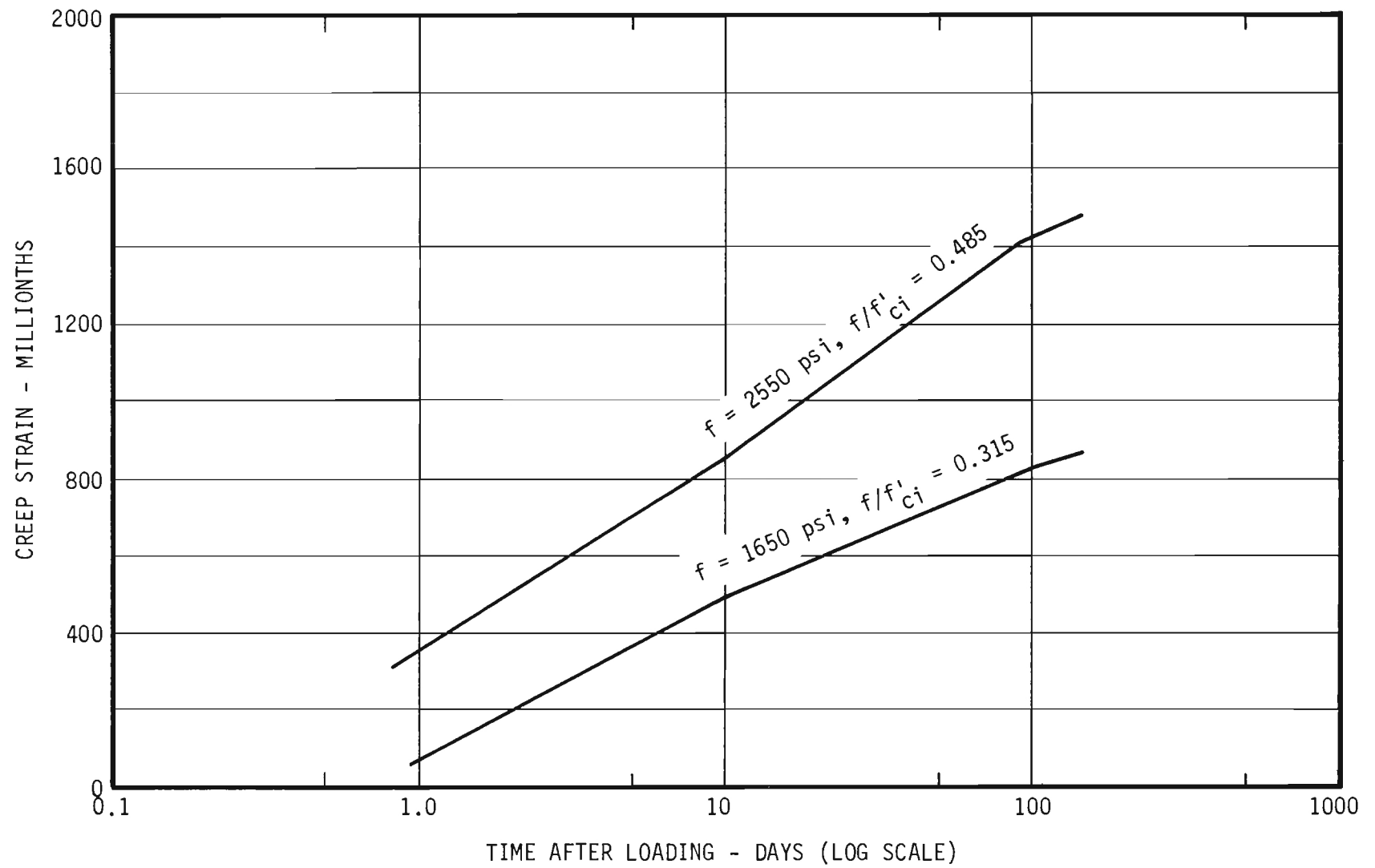


Figure 17. Creep Strain of Clinchlite Semi-lightweight Concrete, Semi-log Plot.

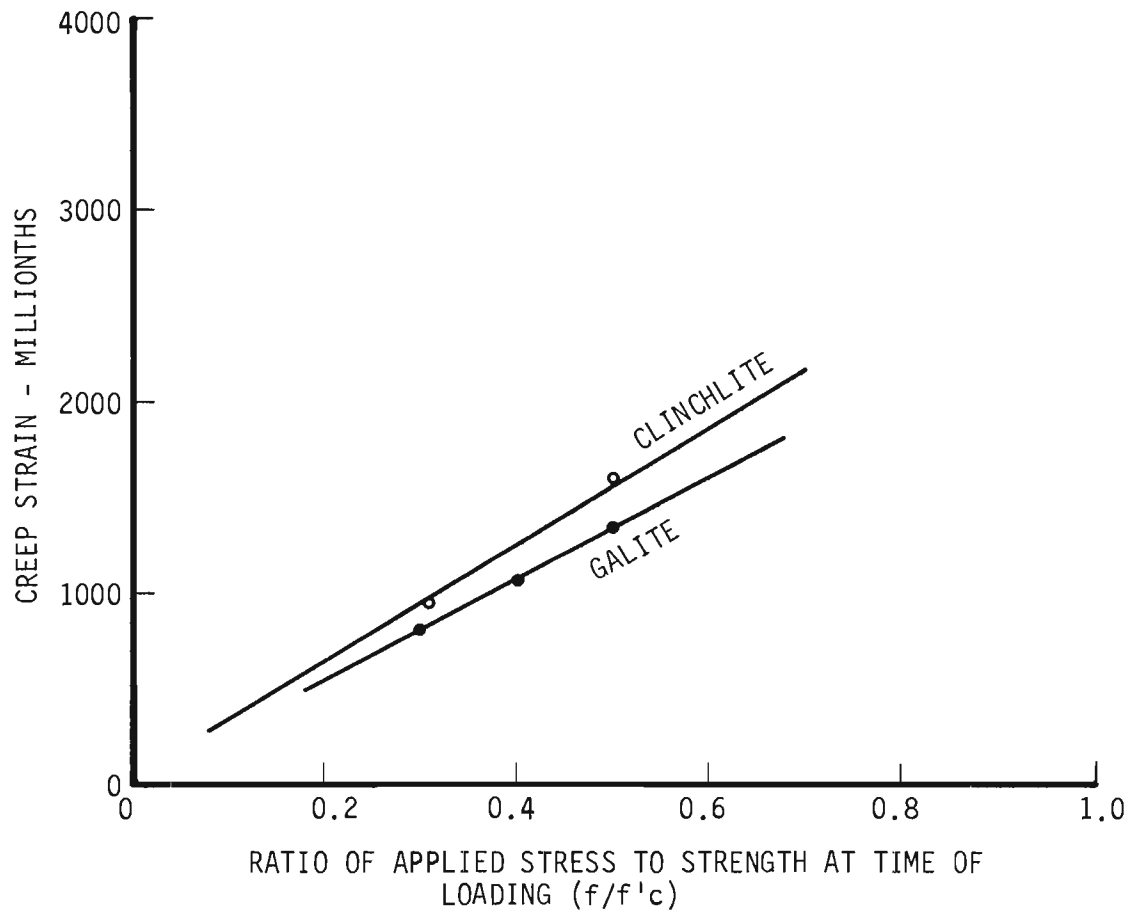


Figure 18. Predicted Terminal Creep Strain vs Stress-strength Ratio.

Results and Conclusions of Static Load Creep Tests

The behavior of concrete under constant stress produces creep curves similar to the shrinkage curves described earlier.

Figure 18 shows the predicted terminal creep strain for both the Galite and the Clinchlite in terms of Creep Strain vs. Stress-Strength ratio. The terminal values were calculated on the basis of a hyperbolic relationship between creep strain and time.

For a given concrete strength, f'_{ci} , Figure 16 can be used to determine a creep coefficient in terms of strain per psi of applied stress. This is illustrated in Figure 19 for $f'_{ci} = 4000$ psi. From this graph creep coefficients have been determined as follows:

	<u>Creep Coefficient</u>
Galite Semi-Lightweight Concrete	0.67×10^{-6} in/in/psi
Clinchlite Semi-Lightweight Concrete	0.77×10^{-6} in/in/psi

Note: These values are based on $f'_{ci} = 4000$ psi

In practice, the prestressed beam will be subject to variable flexural stresses ranging from some maximum value, e.g., $f/f'_{ci} = 0.4$, down to a value of zero. Under such conditions, it would be assumed that the "effective" beam prestress would be $2/3$ of the maximum f/f'_{ci} . Then the terminal creep strain for the beam as a whole could be based on the "effective" prestress value rather than on the maximum prestress value when calculating loss-of-prestress.

The above assumption is substantiated somewhat by the results of the Loss-of-Prestress study reported later, wherein the measured creep strains for a given f/f'_{ci} were lower than under static load conditions.

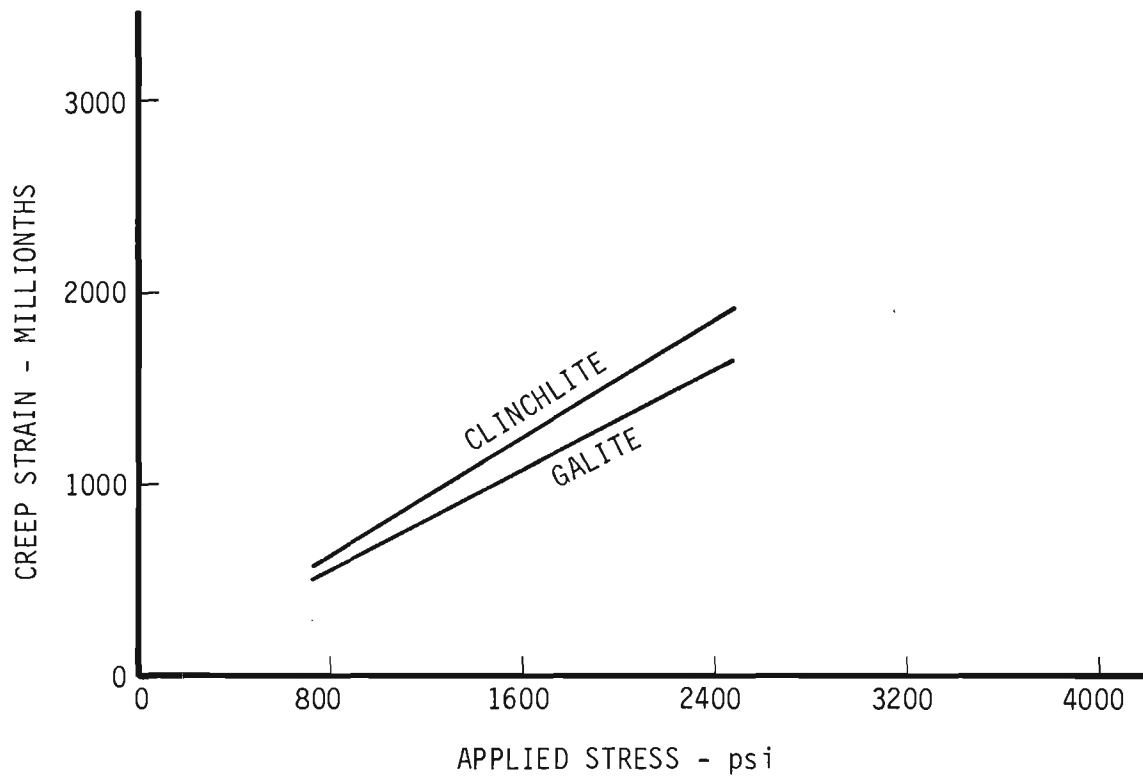


Figure 19. Predicted Terminal Creep Strain vs Applied Stress for Assigned Strength of 4000 psi at Time of Loading.

C. Concrete Creep Under "Prestressing-Type" Loads

In this study cylindrical specimens were subjected to prestress loads which were allowed to vary (diminish) with time as the concrete specimens shortened due to creep and shrinkage. Such conditions are probably more representative of the behavior of a full-sized prestressed member; however, there are other considerations which cannot be accounted for and this type of test also does not correctly represent the field conditions. The value of this test is to determine a lower bound for the creep strain of a prestressed member due to the lowering of the prestress force.

The Galite Semi-Lightweight concrete was tested at 4 days age under two prestress values. Each cylinder load was applied by means of a Stressteel bar passed through an axially located hole cast into the cylinder. The deformation of the specimens were measured by the use of a Whittemore Gage as previously described.

In order to obtain a measure of the effect of age (strength) on the creep of the concrete the Clinchlite Semi-Lightweight concrete was loaded to the same initial value of prestress load at ages of 5, 12 and 19 days.

The results of these tests are shown in Figures 20 through 22.

Results and Conclusions of "Prestressed Cylinder" Study

The strain-time relation of the concrete under this type of diminishing load has a characteristic strain-time curve similar to that of constant-loaded concrete. The creep strain rate is high at early ages and decreases with increasing time. The Creep vs. Time results are shown to arithmetic scales in Figures 20 and 21. It is of interest that there is a considerable decrease in creep strain with increasing age of concrete prior to loading. In terms

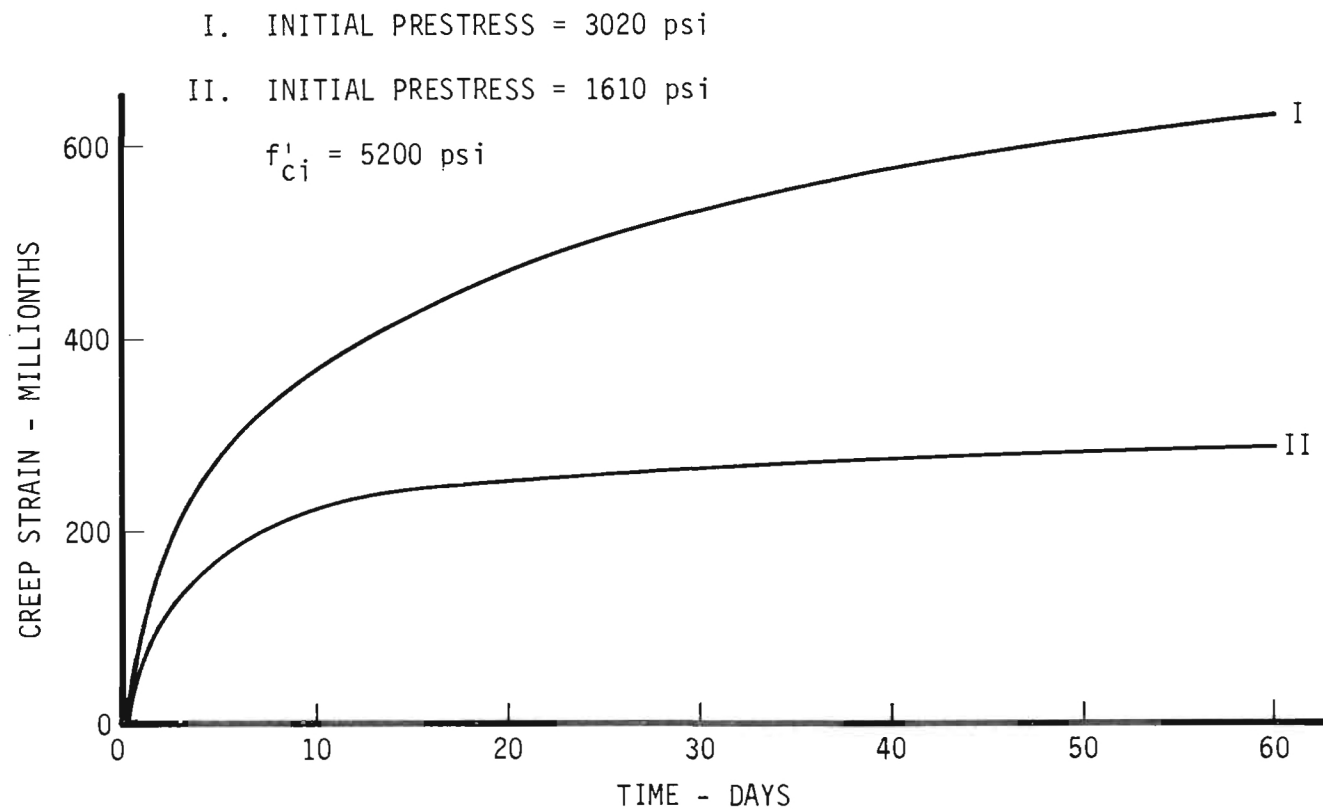


Figure 20. Creep Strain of Prestressed Galite Cylinders under Various Prestress Loads.

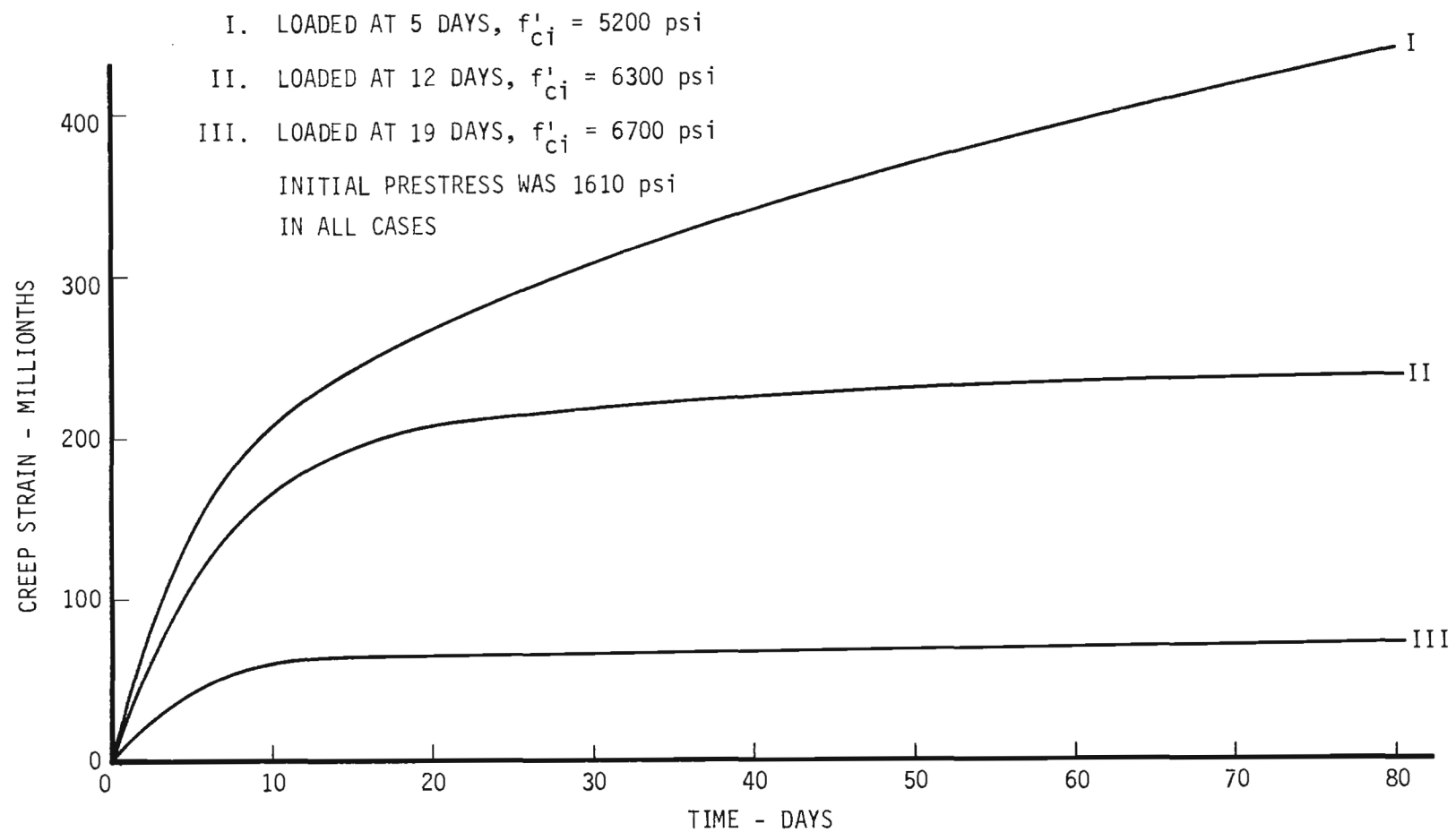


Figure 21. Creep Strain of Prestressed Clinchlite Cylinders Loaded at Various Ages.

- 1 CLINCHLITE SEMI-LIGHTWEIGHT CONCRETE @ 60 DAYS, PRESTRESS LOAD
- 2 GALITE SEMI-LIGHTWEIGHT CONCRETE @ 60 DAYS, PRESTRESS LOAD
- I CLINCHLITE SEMI-LIGHTWEIGHT CONCRETE @ 60 DAYS, CONSTANT LOAD
- II GALITE SEMI-LIGHTWEIGHT CONCRETE @ 60 DAYS, CONSTANT LOAD

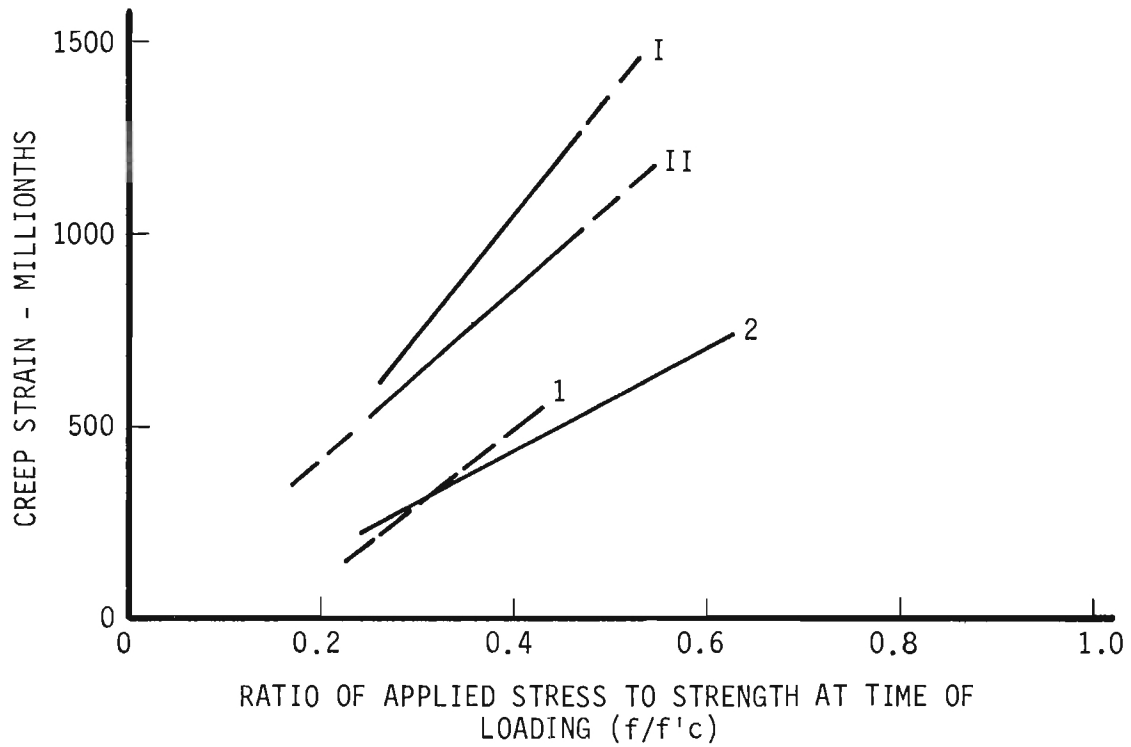


Figure 22. Contrast of Creep Strain for Prestress and Constant Loading.

of construction time, however, there is not sufficient difference to offset the additional time delay. Prior tests for lightweight concrete indicated about the same behavior. Figure 22 shows the results in terms of the Creep Strain versus Stress-Strength ratio and contrasts these results with those of the Constant Load Tests. It is readily apparent that a considerable reduction in creep strain occurs under the prestress-type loading.

D. Loss-of-Prestress Study

The purpose of this test series was to determine the behavior of the concrete under load conditions which approximate those in practice. Prestressed concrete beams and girders are subjected to load conditions which produce flexural stresses in the member. The stresses vary through the depth of the member from approximately zero to the maximum allowable prestress value. These conditions are essentially reproduced in the laboratory-sized beams used in this study.

Beams, 6 in. x 9 in. x 36 in., of both Galite and Clinchlite Semi-Lightweight concrete were eccentrically prestressed in the special loading frames described in Chapter II. The prestressing loads are caused to act at the $1/3$ point of the beam ends with respect to the 9 inch dimension. This induces compressive stresses in the beam which vary linearly from a maximum at one side to zero at the other. As the concrete shortens, (due to creep and shrinkage), there is a loss of the initial prestressing force. By monitoring the prestress force, the loss of prestress with time can be assessed.

Deformation of the specimens was determined by the use of mechanical gage points attached to the exterior faces of the beams. Two sets of gages

were utilized on the face where the prestress was a maximum and on the minimum prestress face. Gage points were attached at $1/3$ and at $2/3$ of the distance between the minimum and the maximum stress faces. Gage points were attached to both sides of these faces in order to obtain average deformations in the event of a slight eccentricity of the load.

The measured deformations of the beams at the gage points were corrected for shrinkage and the deformations due to creep were determined.

Two values of initial prestress load were utilized. For the Galite, the initial load was 60.72 Kips which produced a maximum compressive stress in the concrete of approximately 2250 psi. For the Clinchlite, the initial load was 50.8 Kips which produced a maximum compressive stress of approximately 1880 psi.

The results of this series are shown graphically in Figures 23 through 32.

Results and Conclusions of Loss-of-Prestress Study

The strain vs. time behavior of concrete subjected to stresses which diminish with time due to creep and shrinkage is similar to that of concrete under constant stress with respect to the general shape of the strain-time curves.

Galite. Creep strain vs. time curves for the Galite concrete are shown in Figures 23 and 24.

It is evident that the minimum-stress face of the concrete was under a very slight initial compression. This changed with time, due probably to small geometry changes as creep and shrinkage progressed, until an apparent slight tension was effective as evidenced by negative values of creep strain. These strains are quite small, however, and indicate that the desired stressing action was being closely maintained.

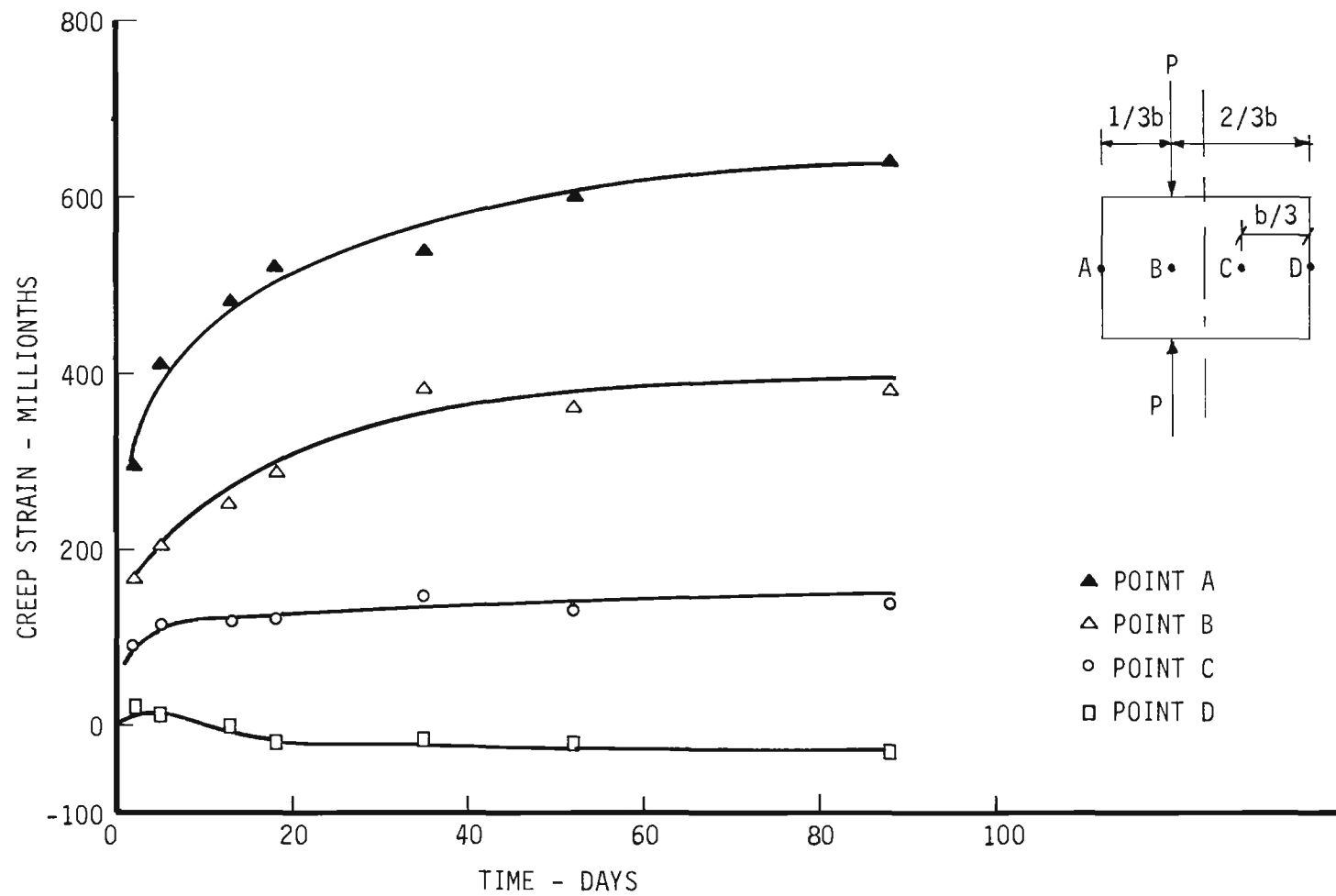


Figure 23. Creep Strain vs Time, Galite Prestressed Beam, Arithmetic Plot.

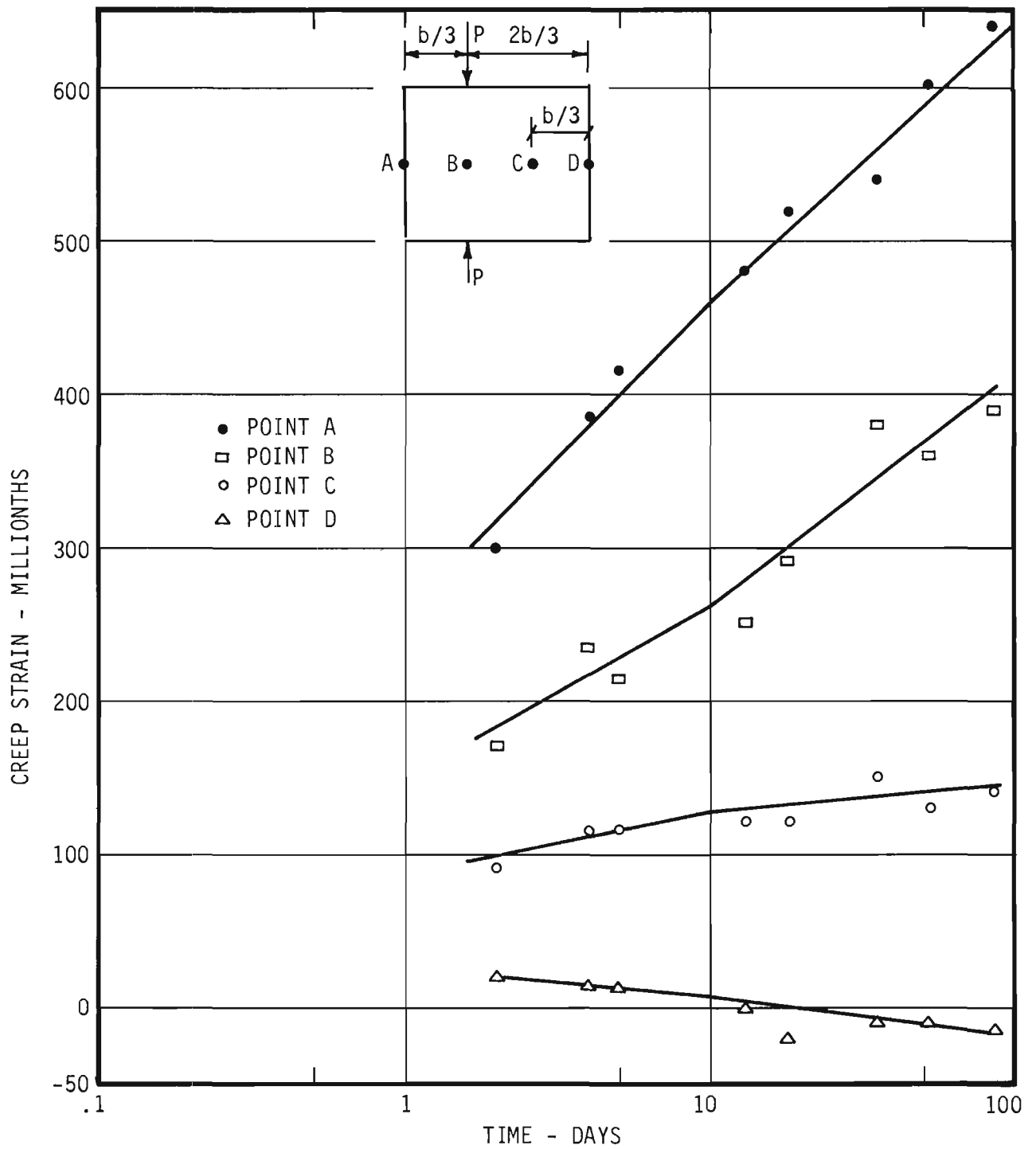


Figure 24. Creep strain vs Time, Galite Prestressed Beam, Semi-log Plot.

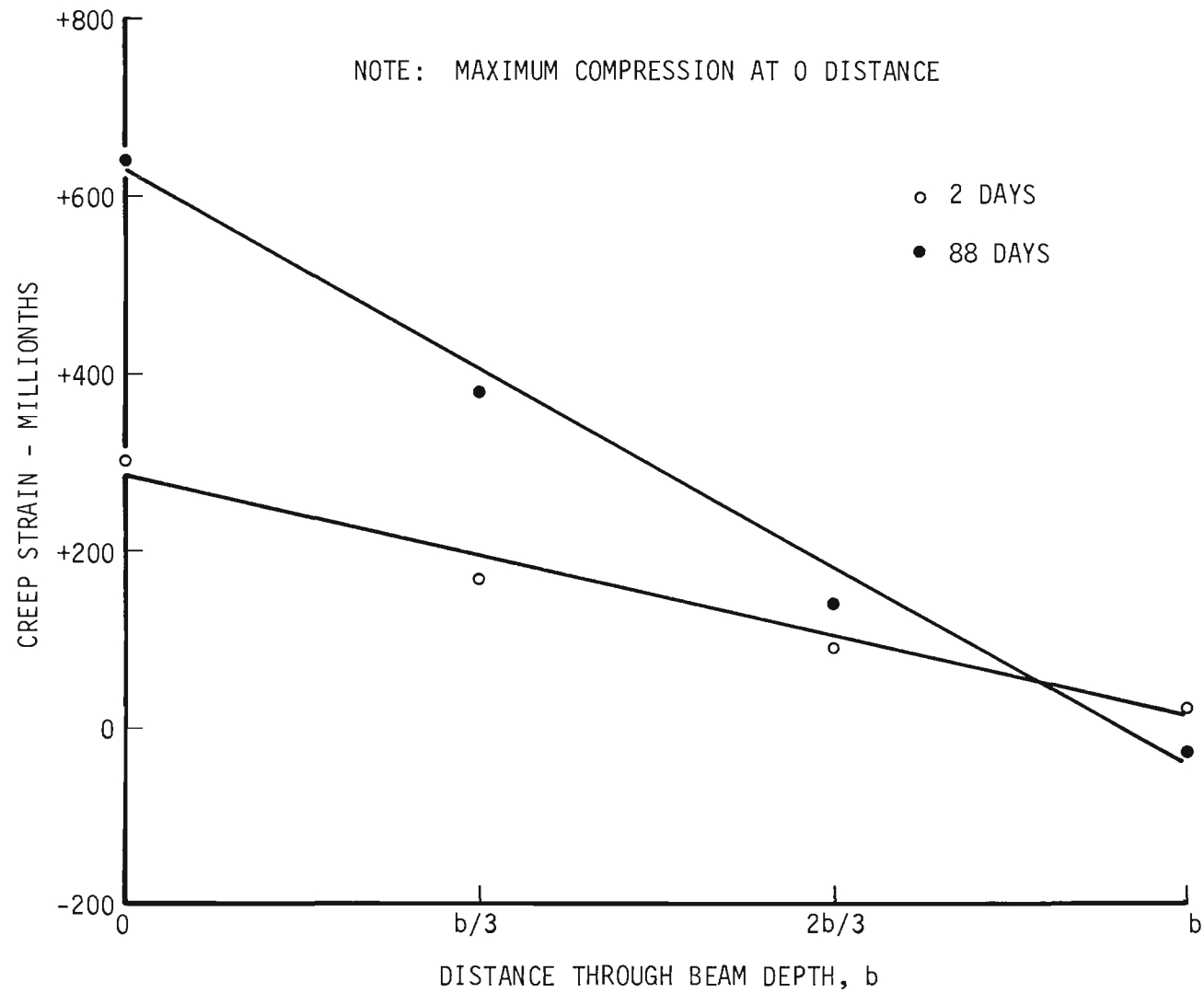


Figure 25. Creep Strain vs Distance through Beam Depth, Galite Prestressed Beam.

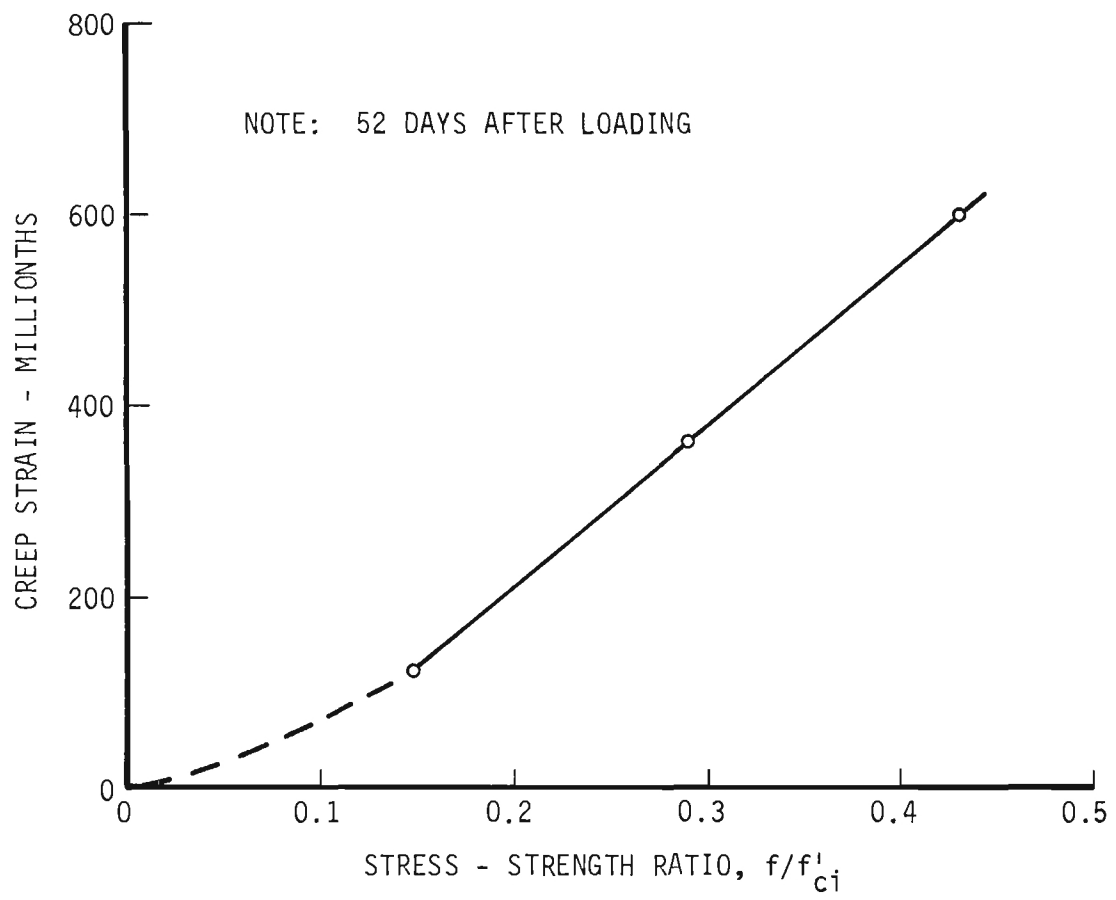


Figure 26. Creep Strain vs Stress-strength Ratio, Galite Prestressed Beam.

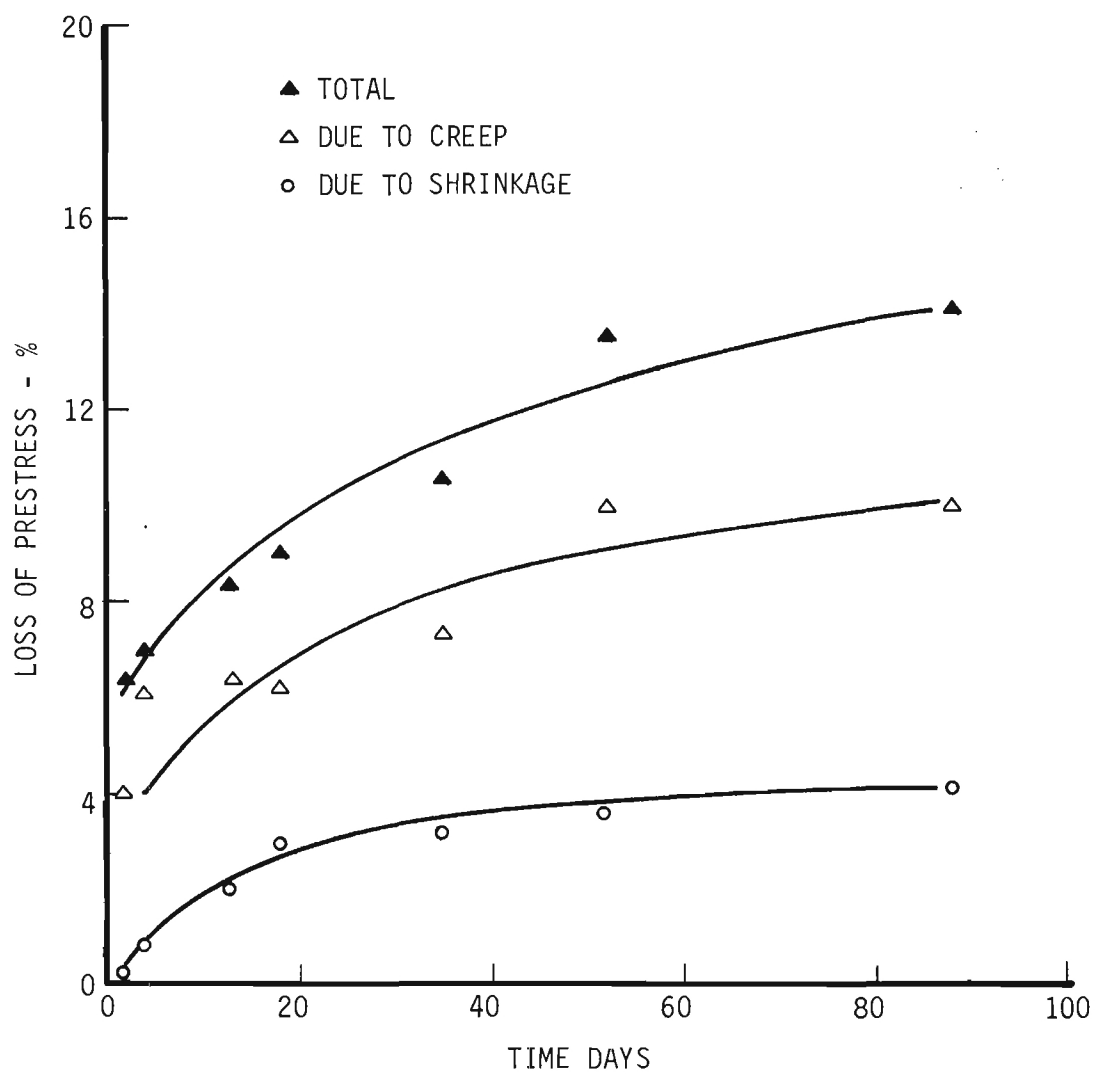


Figure 27. Loss of Prestress, Galite Prestressed Beam.

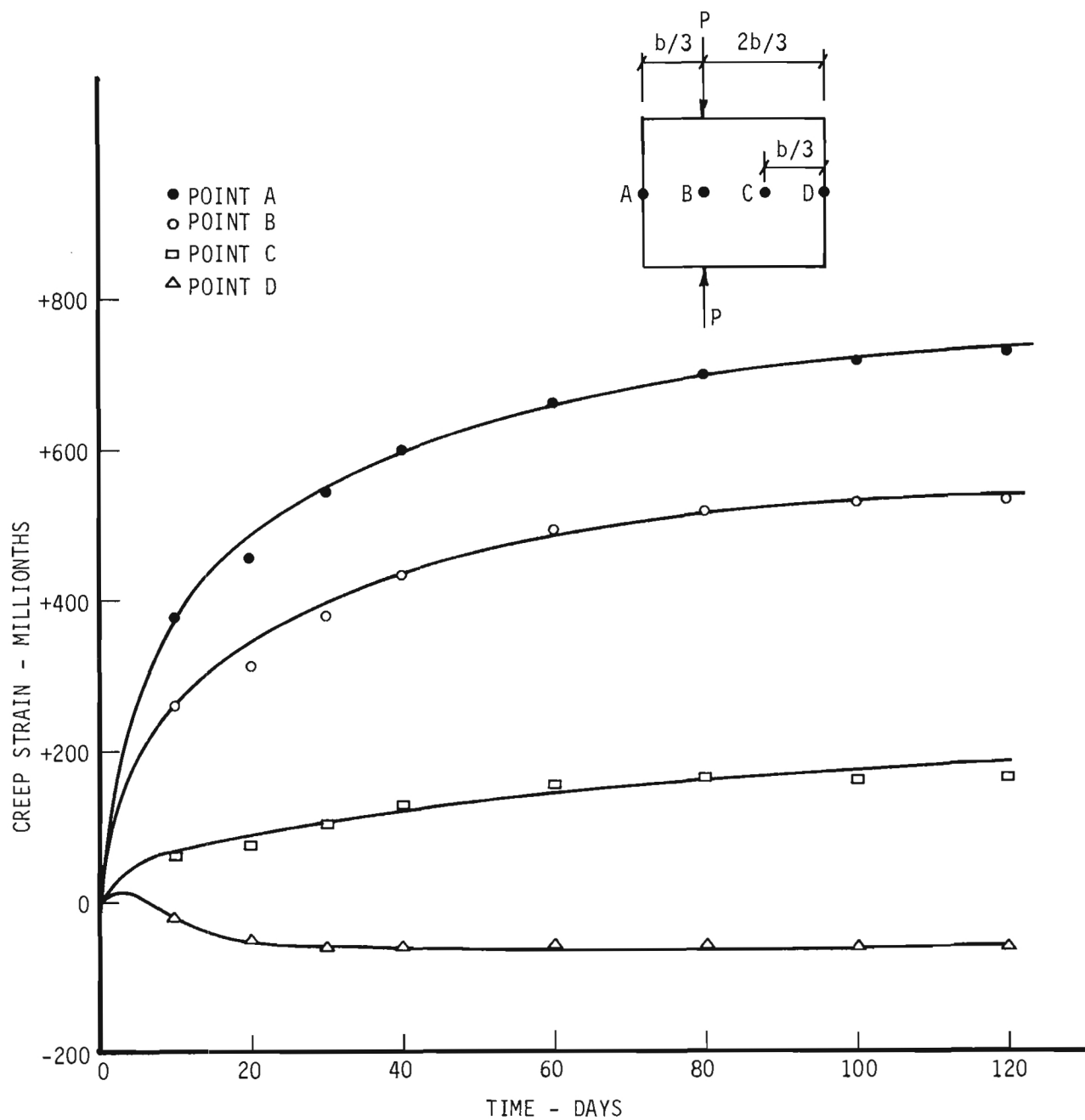


Figure 28. Creep Strain vs Time, Clinchlite Prestressed Beam, Arithmetic Plot.

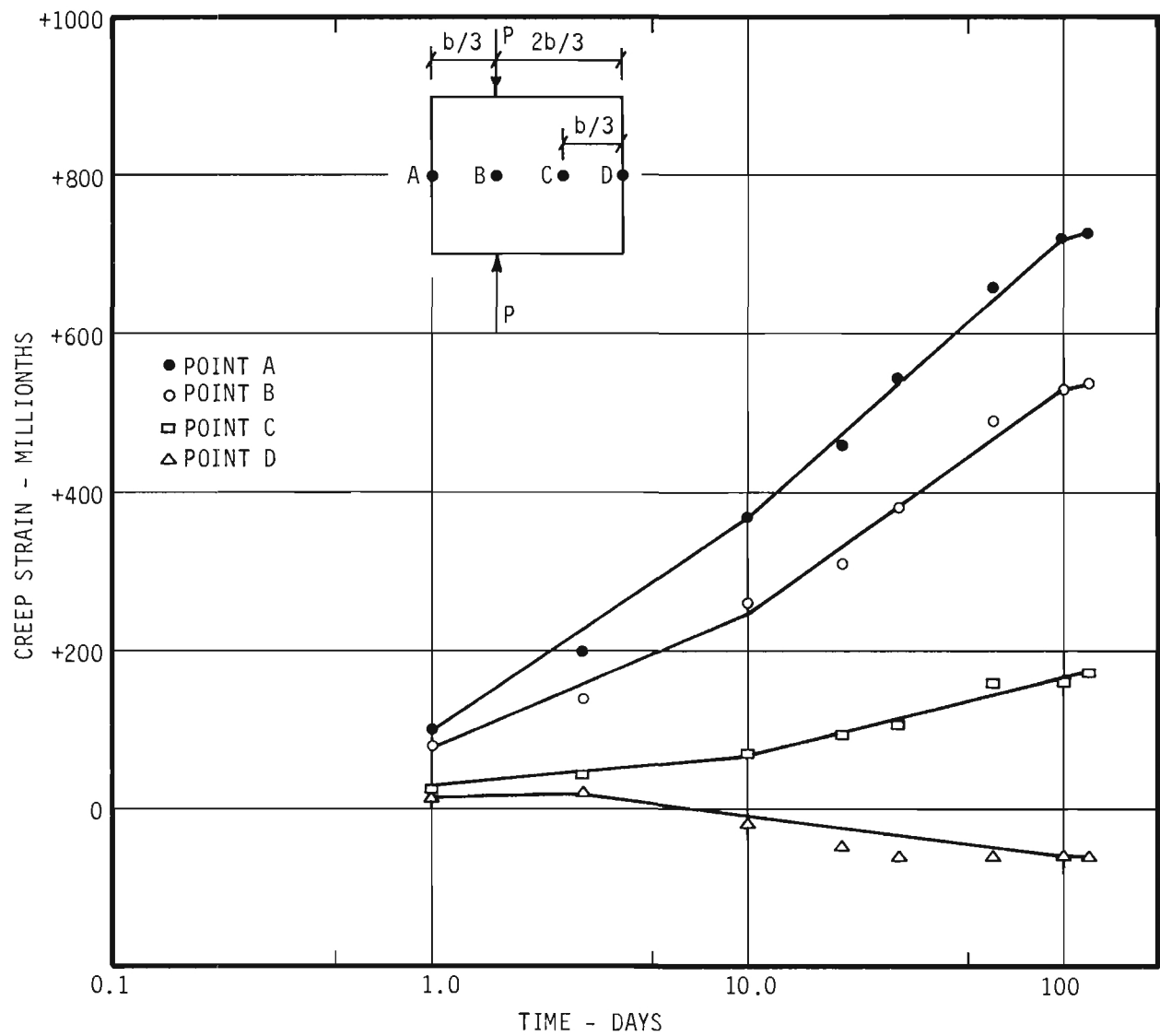


Figure 29. Creep Strain vs Time, Clinchlite Prestressed Beam, Semi-log Plot.

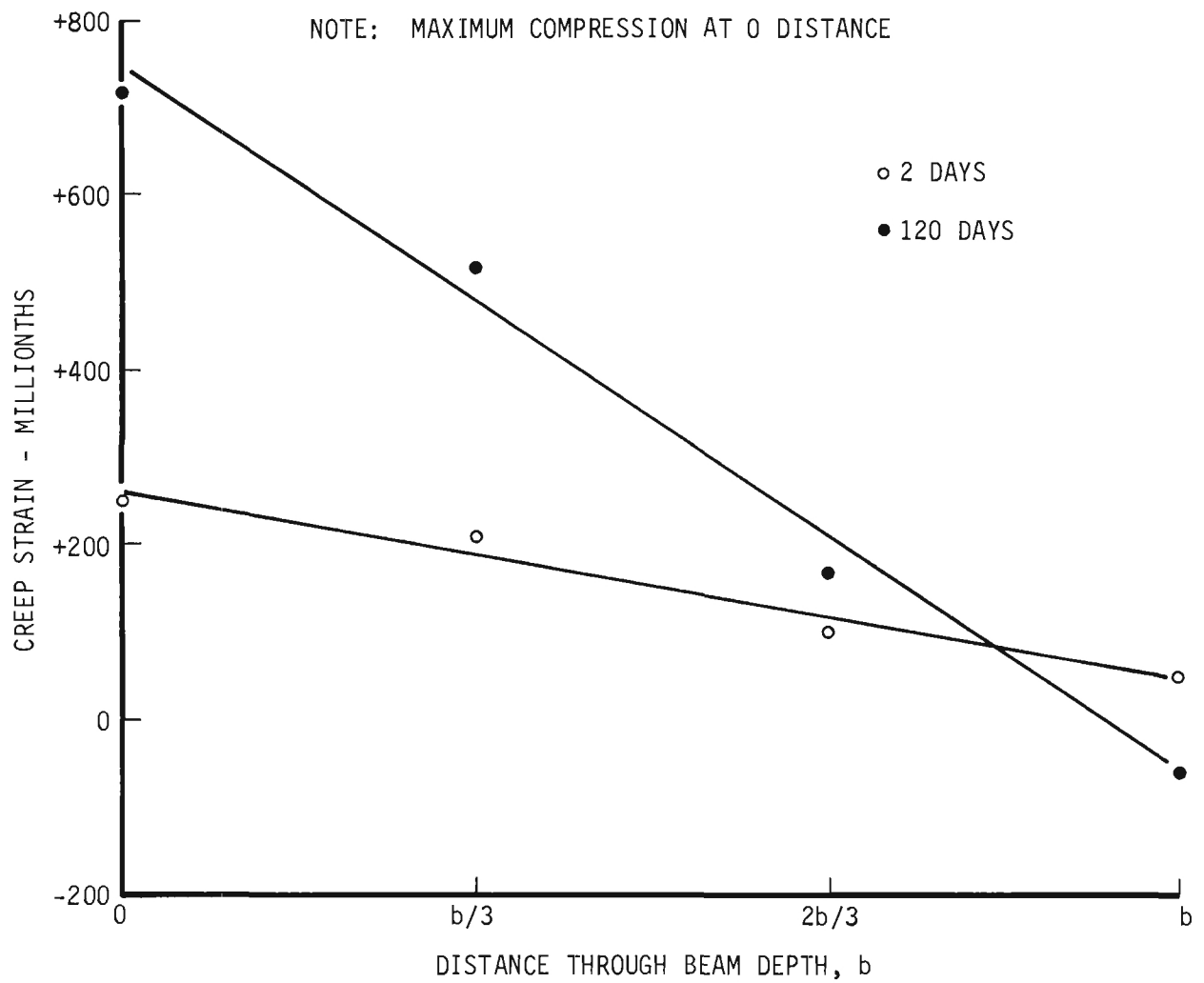


Figure 30. Creep Strain vs Distance through Beam Depth, Clinchlite Prestressed Beam.

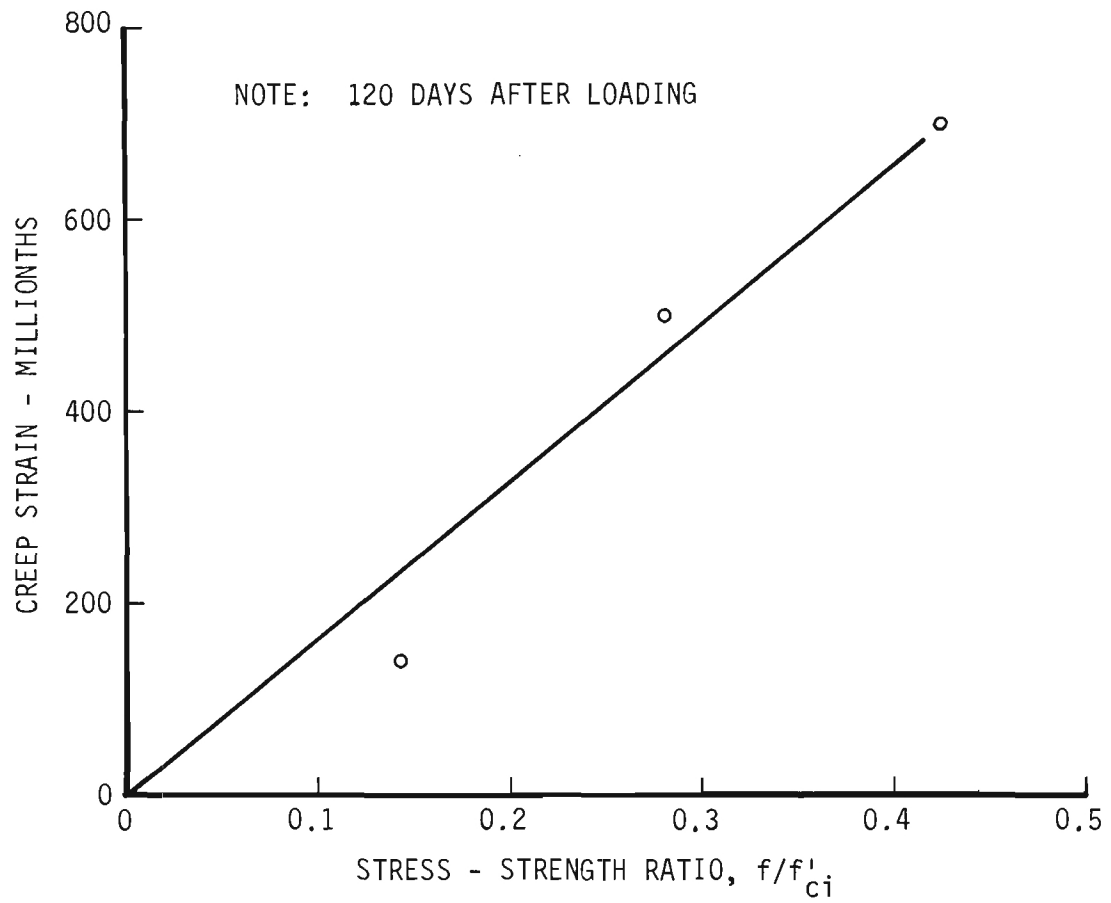


Figure 31. Creep Strain vs Stress-strength Ratio, Clinchlite Prestressed Beam.

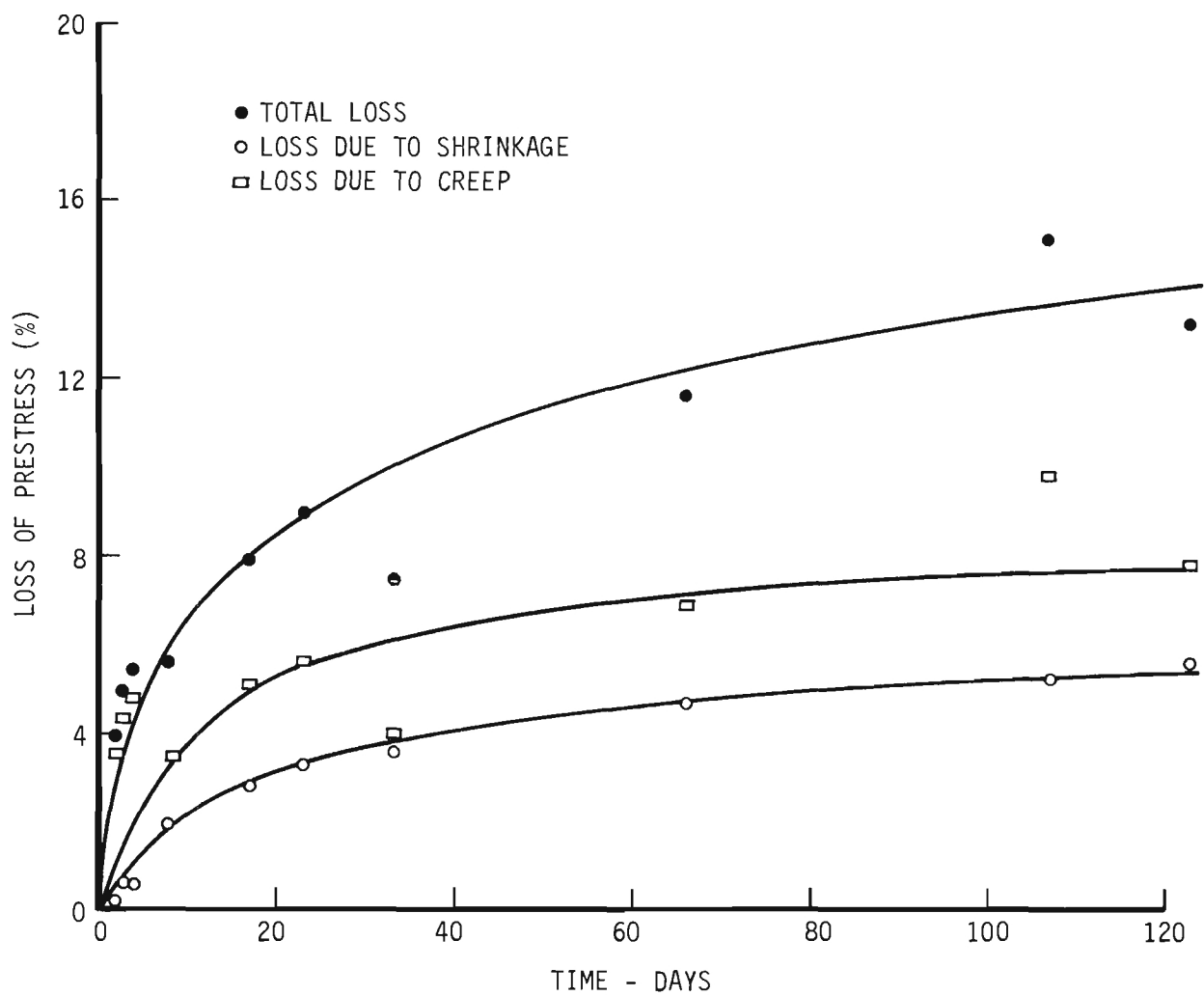


Figure 32. Loss of Prestress, Clinchlite Prestressed Beam.

The magnitude of the initial maximum stress in the concrete with respect to the strength of the concrete at the time of loading was within the range wherein the creep is linear. The creep strain through the depth of the beam should therefore be linear. The variation within the Galite beam is shown in Figure 25 for several ages after loading. The curves are reasonably linear.

Figure 26 shows the relation between creep strain and the stress to strength ratio. The linear relation between the creep and applied stress is also evident in this plot. The magnitude of creep strain is somewhat less for a given value of stress-strength ratio for the beam than is the case for cylindrical specimens. This corresponds with the shrinkage behavior of the two types of members and suggests the possibility of utilizing a reduced creep and shrinkage coefficient for prestressed beams as opposed to values obtained from tests on cylindrical specimens. Due to the limit amount of such data available, however, it is not recommended that any such reduction be made.

The loss-of-prestress for the Galite beam was calculated and the results are shown graphically in Figure 27. This plot shows that the major part of the prestress loss occurs rather quickly and that the final prestress loss will be on the order of 18 percent. While the Prestress Loss is given in terms of percent, it should be recognized that these values were computed from the measured losses and the initial prestress value actually applied. For other initial prestress values, the percent loss due to shrinkage would be in proportion to the ratio of this test load to the actual load.

Clinchlite. The Clinchlite concrete beam behaved quite similar to the Galite beam. Creep strain curves are shown in Figures 28, 29, 30 and 31. The loss of prestress is shown in Figure 32.

It is apparent that both the Galite and the Clinchlite concrete can be expected to behave similarly under flexural stresses to their behavior under direct compression. There will be a somewhat lower total creep strain in a prestressed member than is indicated by direct comparison with constant-loaded cylinders due to the stress-relieving action.

For both the Galite and the Clinchlite, however, it is recommended that the constant-stress creep values be utilized until much more data are available with respect to creep under flexural stresses.

E. Stress Transfer Study

The purpose of this study was to determine the stress transfer-length characteristics of semi-lightweight concrete made from the two lightweight aggregates when prestressed.

The concrete was cast in metal forms to produce prisms $3\frac{1}{2}$ inches in width, 4 inches in height and 8 feet in length. The members were each prestressed with a single $7/16$ inch diameter, conventional pretensioned strand which passed through the center of the concrete. The strands were in "field condition" in that no cleaning of the strands was done; however, the strands were not rusted and would be representative of strands utilized by a commercial prestressing plant which exercised reasonable care in their operations. Each strand was pretensioned to a load of 18.9 kips. This produced a maximum prestress in the concrete of 1575 psi.

Mechanical gage points were attached to both of the $3\frac{1}{2}$ inch faces of the specimens at the level of the prestressing strand. The gages were located at intervals of 2 inches along the beams beginning 4 inches from an end and extending about 36 inches. A Whittemore mechanical gage was used to measure deformations between the gage points immediately prior to and after the detensioning.

The stress transferred at any position along the beam was assumed to be proportional to the deformation which occurred at that position. The prestress transferred to that which occurred in the section where the deformation became constant.

The results are shown in Figure 33 as graphs of Percent of Steel Stress Transferred versus Distance From End of Member.

For both semi-lightweight concretes tested, the full prestress force was transferred at a distance of approximately 25 inches from the "cut end" of the members.

F. Full-Sized Bridge Girder Study

Three full-sized prestressed bridge girders were instrumented and constructed. These girders were 40 feet in length with standard dimensions according to Georgia State Highway Department specifications without end blocks. Each of the girders was made with different concrete. One was of normal weight concrete, one was of Galite semi-lightweight concrete and one was of Clinchlite semi-lightweight concrete. These were cast in the production facilities of the Macon Prestressed Concrete Company, Macon, Georgia. They were cast in line on the same bed, utilizing the same prestress strands.

It was originally planned to monitor both the prestress force in the strands as well as the concrete strains by means of SR-4 resistance gages cemented to the strands prior to the casting and to the outer surface of the concrete subsequent to stripping of the forms. Additionally, mechanical gage points were to be applied to the exterior of the concrete for deformation measurements.

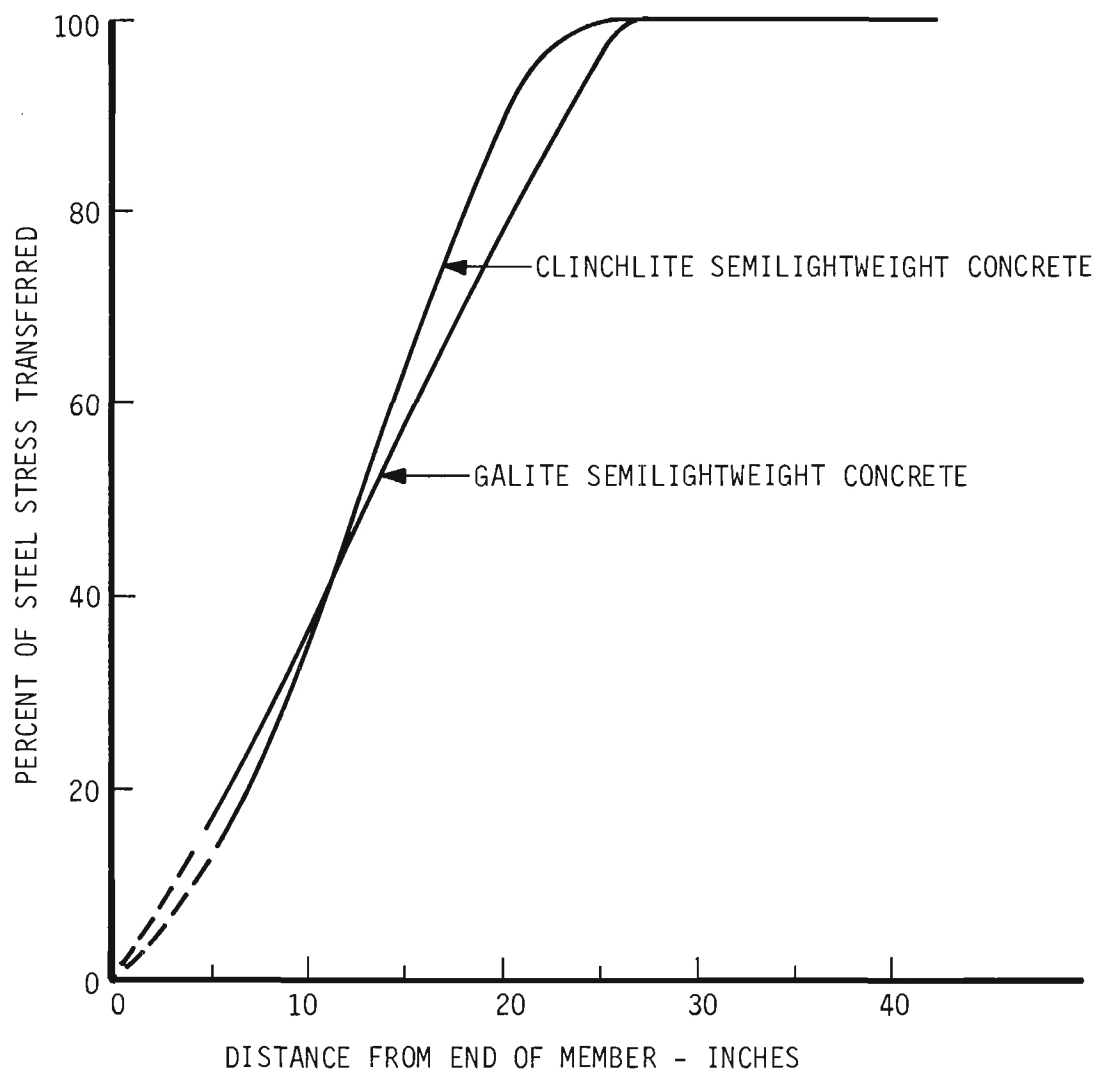


Figure 33. Stress Transfer-length Relation for Semi-light Concrete.

Laboratory checks were made on the gage application techniques as well as a field check under actual prestressing construction operations. Results from the lab work as well as from the field check indicated that the intended techniques would be satisfactory.

The prestressing strands were placed in position and tensioned with a "pre-load" force of 1000 pounds, as is standard operating procedure with the company. This is to take-out most of the slack in the prestressing system and to have a base-length from which to measure elongation of the strands. After the "pre-loading", epoxy cement "patches" were applied to the strands at certain locations and the strain gages were cemented to the epoxy. The lead wires were brought-out from the girder forms, the gage installations were water-proofed and the strands were stressed to their full prestress level. The stressing of the strands was monitored with the strain gage installations and a very good correlation was found between the prestress loads as measured by the gages and the prestress loads as determined by the elongation of the strands.

The girders were cast one at a time in order to utilize the one set of forms available. After the removal of the forms the exterior resistance gages were applied and the girders were prestressed by cutting the strands in a pattern as would be done in practice.

It was found that many of the strain gages had been either shortened by moisture or damaged during the concreting operations. It appeared at first that a sufficient quantity were in good working order and that the data being taken would be of satisfactory quality. Close examination of the reduced data, however, shows that there is no meaningful correlation even between deformation and time for a given gage. For instance, many of the

gages on the strands indicate prestress losses greater than the original prestress force by factors of two or three. There are many concrete deformations indicated which would necessitate compressive failure of the concrete.

It is concluded that this portion of the testing program has not produced meaningful data with respect to the creep and loss-of-prestress behavior of the concretes. The erratic behavior of the strain gages is, of course, the source of the poor data. Attempts to understand the gage performance lead to the following conclusions:

1. The immediate shorting of gages was probably due to poor waterproofing.
2. Later shorting of gages could be due to either poor waterproofing, or a migration of moisture through the expoxy "patches" on which the gages were cemented.
3. Lost gages were attributable to damage during the concreting operations or to damage at the time of the strand cutting.

At the time of the instrumenting of the strands as well as of the beam exterior, the humidity was extremely high. It is possible that much of the poor performance of the gages can be attributed to the effect of the humidity on the porosity of the epoxy.

CHAPTER V

SUMMARY OF RESULTS AND CONCLUSIONS

Results of the testing program and conclusions derived therefrom are summarized as follows:

A. Use of Galite and Clinchlite Aggregate in semi-lightweight concrete for prestressed bridge girders is quite practical. Prestressed members of good quality have been produced from semi-lightweight concrete made from each of the aggregates.

B. Each of the two aggregates is capable of producing semi-lightweight concrete having strengths which meet the requirements of the Georgia State Highway Department specifications for prestressed concrete bridge girders.

C. The static secant modulus of elasticity for both the Galite concrete and the Clinchlite concrete is approximately 3.05×10^6 psi at 3 days of age using Type III Portland Cement and moist curing techniques.

D. Shrinkage of the two semi-lightweight concretes is calculated to be as follows:

<u>Concrete</u>	<u>Terminal Shrinkage-millionths*</u>
Galite	790
Clinchlite	530

E. Creep of both the galite and the Clinchlite semi-lightweight concrete is approximately proportional to the Stress-Strength Ratio** for values of applied stresses up to and greater than those ordinarily used in prestressed work.

*One millionth = 1×10^{-6} strain units (inches per inch).

**The Stress-Strength Ratio is the ratio of the applied compressive stress to the compressive strength at prestress age, f/f'_{ci} .

F. Creep coefficients for $f'_{ci} = 4000$ psi compressive strength are as follows for constant loading conditions:

<u>Concrete</u>	<u>Creep Coefficient</u>
Galite Semi-Lightweight Concrete	0.67×10^{-6} in/in/psi
Clinchlite Semi-Lightweight Concrete	0.77×10^{-6} in/in/psi

G. Prestress-type loading of beams and cylinders indicate that lesser creep will occur in prestressed members due to the unloading effect of creep and shrinkage (as well as relaxation), however, no value can be assigned to such reductions from presently available data.

H. Loss of Prestress for both the Galite and the Clinchlite semi-lightweight concretes is approximately 18 percent* due to the combined effect of creep and shrinkage.

I. The stress-transfer characteristics of both concretes are satisfactory and the full prestress force will be transmitted to the concrete within 30 inches for a 7/16 inch conventional pretensioned strand.

*This value is dependent upon the initial prestress force among other things and should be used with caution.

CHAPTER VI

RECOMMENDATIONS

The results of this investigation have indicated the difficulty of making a rational analysis of the loss of prestress in prestressed concrete members regardless of the aggregate used in the construction. It has been well established that factors such as aggregate type, concrete composition, specimen shape and size, and character of loading as well as others all influence the loss of prestress in a prestressed member. Efforts to interrelate the effects of some of these variables have been relatively unsuccessful. Although some generalizations can be made, it appears that an assigned value for total prestress loss is still the only practical solution at the present time. These results indicate that the combined total loss due to creep and shrinkage should not be greater than 20% for concrete made with either of the two aggregates tested.

It has been considered good practice to delay the beam-stressing operation (i.e. cutting of strands in pretensioned work) for as long as economically possible in order to reduce the prestress losses due to shrinkage of the concrete. The present test results indicate no great benefits from such delays since the creep and shrinkage losses are interrelated and a reduction in shrinkage losses tends to be offset by greater creep losses. Therefore, from a prestress loss point-of-view, the benefits of delayed stressing will be derived primarily from elastic shortening and camber considerations.

Further attempts to define the behavior of prestressed concrete on a rational basis by the use of material properties are necessary in order to advance the art of prestressed work. Among the more promising areas for

research would appear the following:

A. Laboratory-sized beams prestressed by external means similar to that used in this study. Variables should include initial prestress level, concrete proportions, and environmental conditions (temperature and humidity).

B. Instrumentation of full sized members, in an "unloaded" condition as well as "in service" situations in order to observe the behavior of the members with time and under service loads. The "unloaded" members could be subjected to static load tests to failure.

C. Investigation of the effects of repetitive loading on creep of prestressed members.

CHAPTER VII

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3. Hanson, T. C. and A. Mattock, "Influence of Size and Shape of Member on the Shrinkage and Creep of Concrete," Journal of the A.C.I., Proceedings, Vol. 63, February, 1966.